2024/25 Coffee Harvest Season Experiment Report

Impact of Stumping *Coffea arabica* Trees on the Physical and Sensorial Attributes of Resulting Coffee Samples

Photo Credit: Dula Afework

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Abstract

Rejuvenation or stumping is widely promoted for restoring yield in aging *Coffea arabica* stands, yet its full quality and economic impacts remain poorly quantified. We compared stumped (2-year regrowth) and unstumped (> 25 yr) trees across low-, mid-, and high-elevation farms in Ethiopia's Gedeo Zone. From 58 trial lots we tracked cherry composition, Brix, cherry and bean mass, green-defect profiles, and sensory scores.

On average and across all sites, stumping raised the proportion of ripe cherry delivered by 15.3 %, cut human independent and human biased green defects by 29.9 % and 28.9 % respectively, reduced bean breakage during hulling by 35.3 %, reduced under screen (screen-14) beans by 29.2% and improved cup scores by 2.5 cup points.

Further economic modelling estimates that rejuvenation can decrease operational profit losses by ≈$2,870.00 USD in defect-related losses per container produced. Moreover, stumping can generate an additional ≈$21,200.00 USD in price premiums from higher cup scores thereby netting ≈ $24,000.00 USD more per container produced and exported*.

These results show that stumping is not solely a mechanism to maintain or boost farm yields. Stumping measurably elevated the physical quality and sensory value of coffee. From this study, the broad adoption of systematic coffee rejuvenation practices could boost farm productivity and coffee quality thereby strengthening the resiliency of coffee producers. Additionally, by increasing the market competitiveness of Ethiopian coffee, stumping can improve the economic resiliency of the national coffee sector. Based on these findings, it is strongly encouraged that managers and authorities alike, promote the adoption of stumping as a means of bolstering the livelihoods coffee producers and the coffee sectors as a whole.

**The prices presented are illustrative estimates subject to numerous assumptions. They are not guarantees or quotes and should not be relied upon for your specific business or coffee operations.*

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Introduction

Coffee (*Coffea arabica*) is an economically significant agricultural product. Globally, coffee sustains an expansive and dynamic industry valued at approximately 120 to +400 billion USD annually (CMI 2025, GVR 2022, Statista 2024), depending upon the scope of observration; and in many producing nations, coffee represents a significant economic driver at both local and national scales. At the core of this vast industry lie approximately 12.5 million coffee farms (Rushton 2019) whose productivity directly influences the livelihoods of at least 25 million people. Unfortunately, coffee yields in many producing countries, including Ethiopia, remain both low and increasingly unstable due to constraints such as lack of market incentivization, knowledge gaps, limited access to agricultural inputs, and poor agronomic practices. These challenges threaten farm productivity, farmer incomes, and overall resilience which is further exacerbated by increasingly variable and unfavorable climatic conditions.

While no single intervention can resolve these complex issues, increasing farm income represents a critical pathway to building resilience. Higher incomes enable farmers to reinvest in improved agronomic and climate-smart practices, thereby strengthening farm productivity and resiliency. These income gains can be achieved by increasing either the quantity or the quality of coffee produced, both of which warrant greater attention. Ensuring farmer success is not merely a development objective but a strategic industry priority, as the global coffee sector remains wholly dependent on the health and viability of these farms.

One accessible but underutilized agronomic intervention known for enhancing coffee productivity is tree rejuvenation, commonly known as stumping. This practice involves cutting old coffee trees back to stimulate new shoot regrowth which significantly boost productivity in subsequent harvest cycles. Stumping has shown substantial yield improvements within Ethiopia (Anteneh, 2015; Anteneh et al., 2008) and in other coffee-growing regions around the World (Canell 1983, Darfur et al. 2019, Gokavi et al. 2021, Jativa 1990, Netsere 2006).

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Despite well-documented benefits for boosting yield, relatively limited research has explored how stumping influences coffee quality, particularly in terms of physical (green bean) and sensory (cup) attributes. As global demand for premium and specialty coffees continues to rise, understanding the effects of rejuvenation on cup quality is increasingly important. Moreover, stumping may also reduce the occurrence of green bean defects, thereby increasing the turnout of marketable, high-quality coffee. By enhancing both the sensory profile and physical quality of coffee beans, rejuvenation practices may have greater potential to improve farm incomes and producer resilience beyond simply farm yield improvements.

This study aimed to address this knowledge gap by systematically evaluating the impacts of stumping on coffee bean quality in Ethiopia's renowned Gedeo Zone, the origin of the widely recognized Yirgacheffe coffee. Specifically, we analyzed differences in cherry composition, sugar content, cherry mass, green bean quality (density, bean size, primary and secondary defects), and sensory attributes between stumped and unstumped coffee trees. The insights derived from this research can directly contribute to better understanding of the impacts of rejuvenation on coffee quality to provide information to aid evidence-based decision making within the Ethiopian coffee sector.

Scope

The topography of the Gedeo Zone of the Southern Ethiopia Regional State (SERS), is comprised of steep terrain that varies significantly in elevation from ~1,250 m.a.s.l. to ~3,000 m.a.s.l. These elevational changes significantly influence both the agronomic conditions and post-harvest processing practices within the region. To account for this variability, three experimental areas were selected to span and represent this elevational gradient. By selecting farm sites and experimental processing facilities at low (<1,700 m.a.s.l.), mid (1,700 – 1,900 m.a.s.l.), and high (>1,900 m.a.s.l.) altitudes, and by mimicking local construction practices and processing methods, we sought to capture a series of representative cross-sections of production environments as found within the Gedeo Zone. This approach was designed to enhance the

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robustness and relevance of findings, offering more comprehensive insights into how stumping affects coffee quality across elevational gradients.

The lowland site was established at the TechnoServe (TNS) office in Dilla (~1,500 m.a.s.l.), with coffee cherry sourced from farms in the neighboring Gola Kebele (village) situated below 1,700 m.a.s.l. This site served as the primary low-elevation reference for the study. The midland site was located in Wonago at the Hase Haru Cooperative, a member of the Yirgacheffe Coffee Farmers' Cooperative Union, and situated at approximately 1,750 m.a.s.l. Cherry for this site was sourced from nearby farms in Hase Haru and Kelecha Kebeles ranging between 1,700 and 1,900 m.a.s.l. The highland site was constructed in Dumerso at the Dumerso 23 Cooperative, also part of the Yirgacheffe Coffee Farmers Cooperative Union. The processing site was constructed at ~1,885 m.a.s.l. and just below the 1,900 m.a.s.l. threshold of the highland gradient. The original site was intended to be above 1,900 m.a.s.l. and closer to the selected farms, but prolonged rains during the 2024/25 harvest season made the planned site inaccessible. The constructed processing site was selected for its proximity to all-weather roads, ensuring continuous access by field staff. Farms contributing to this site were located in Ela Tenecha and Berbeskela Kebeles and located above 1,900 m.a.s.l., consistent with our definition of the highland category (Figure 01).

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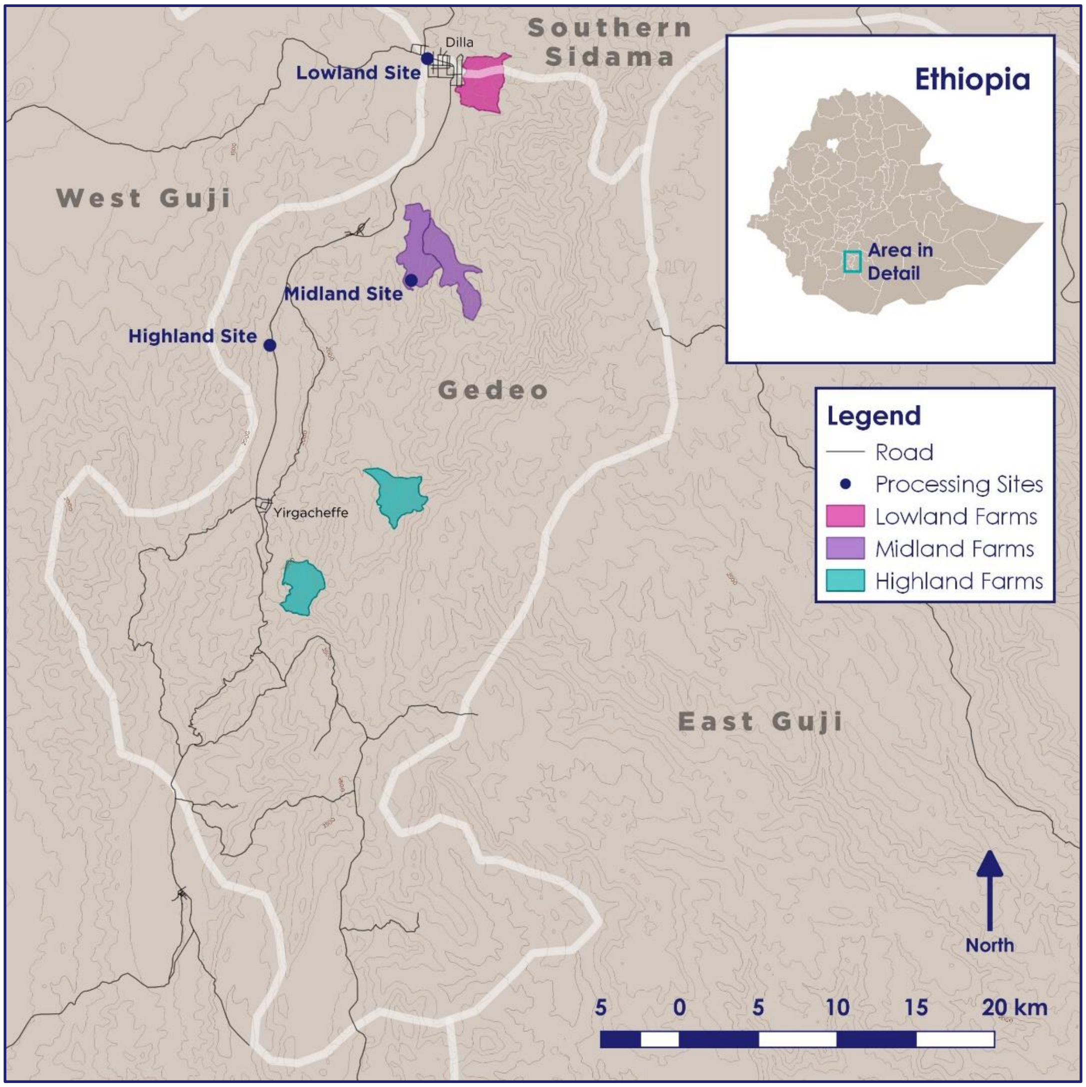

Figure 01. Locations of experimental processing sites and selected farmer kebeles (villages) in the Gedio Zone, SERS for the coffee harvest season of 2024/25.

Methodology

Farm Selection and Preparation

Farm sites were selected in collaboration with TNS agronomy staff based on several criteria including elevation, time of stumping, number of stumped trees, number and age of unstumped trees, agronomic practices utilized on the farm and distance to experimental processing facility. Firstly, farms were chosen within the designated elevational zones, low (<1,700 m.a.s.l.), mid (1,700–1,900 m.a.s.l.), and high (>1,900 m.a.s.l.). They were also required to have stumped at least 50 trees during the first year

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of the Regrow Yirga Project in 2022. This ensured sufficient regrowth and fruiting capacity by the 2024/25 harvest season to fulfil required cherry volumes. In addition, selected farms needed to include a minimum of 50 unstumped trees with a reported age of at least 25 years, which would serve as the control or unstumped group for comparison.

To control for potential confounding effects related to agronomic practices, farms demonstrating consistent implementation of best agronomic coffee practices such as mulching, composting, pruning, weeding, shade regulation, etc. were selected for the study. By selecting farms with similar management systems, we aimed to isolate the effects of stumping on coffee quality by minimizing variability of agronomic practices. Respective proximity to the experimental processing sites was also a key consideration during selection. Farms were selected to be as close as possible to their corresponding sites to reduce the time between harvest and delivery and minimize post-harvest quality degradation associated with the transportation of cherry.

Once farms were selected, discussions were held with each farmer to explain the study objectives, provide clear instructions, obtain informed consent, and ensure compliance with harvest protocols. Because coffee trees do not produce 100% ripe cherry in any given harvest with some cherry always failing to ripen, trees needed to be harvested in their entirety to ensure proper cherry and green coffee comparisons. To ensure this, production estimates of stumped and unstumped trees at each site were completed to identify the number of trees necessary to produce sufficient green coffee for later analysis. Once determined, trees were selected then marked at their bases with red paint with farmers, who were instructed to harvest only red, ripe cherries from these marked trees during the harvest season. At the end of the harvest season, during the final cherry delivery, farmers were instructed to harvest all cherry, including unripe, for delivery to their respective processing sites. This protocol allowed for us to complete a comprehensive comparison of stumped and unstumped coffees by ensuring all cherry was accounted for.

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Experimental Site Selection and Construction

Each experimental site was constructed to mirror the prevailing processing practices in the Gedeo Zone. All facilities included raised drying beds of at least 1m in height, constructed using eucalyptus frames and topped with wire and bamboo covered in black shade netting. Bed width varied from one to 1.5 meters, and lengths from five to ten meters. Between three to four beds were constructed at each site. To ensure regulatory compliance and facilitate cherry delivery, experimental sites were established either within the compounds of Regrow Yirga Project partner wet mills or TNS-managed facilities.

Cherry Acquisition and Processing

At the lowland site, coffee cherry was sourced from three farm sites in the Gola Kebele within the Dilla Zuri Woreda (district) at elevations < 1,700 m.a.s.l. At the midland site, cherry was sourced from four farm sites in the Hase Haru and Kelecha Kebeles between 1,700 and 1,900 m.a.s.l. At the highland processing site, cherry was collected from four farm sites in Ela Tenecha and Berbeskela Kebeles with elevations > 2,000 m.a.s.l. Cherry deliveries were scheduled once per week per farm, allowing sufficient time for fruit to ripen between harvest intervals and not overburdening processing facilities. Farmers were instructed to try to pick only ripe coffee cherry for delivery to the experimental processing sites and to keep cherry from stumped and unstumped labelled and stored separately. Again, at the end of the experimental harvest season farmers were instructed to harvest and deliver all remaining cherry from marked trees.

Upon receipt at each experiment processing facility, coffee cherry was floated in water to removed floaters. Cherry was then sorted by ripeness on the drying beds. Defect cherry, floaters and red ripe cherry were then weighed to determine differences in the composition of cherry production between stumped and unstumped coffee.

To further characterize cherry quality, both Brix (a proxy for % sugar content) and the cherry mass were measured ten times for each delivery for both stumped and unstumped coffee. When recording cherry mass, 50 ripe cherries were selected at random and weighed with a digital scale which was then repeated ten times. This

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data was collected to identify any differences in the sugar content and the mass of ripe cherry between stumped and unstumped coffee. Once all measurements were taken, reject coffee composed of floaters and sorted reject cherry, were blended and dried separately from the ripe sorted coffee cherry.

Drying

Immediately following sorting and measurements, coffee cherry was spread into layers of ~3 cm thickness on drying beds. During drying, the cherry mass was rotated thoroughly at two-hour intervals throughout the day to promote even drying. Cherry was covered with shade netting during the extreme heat of the day 11:00 - 14:00 hours. At night and during rainfall events, cherry was covered by both shade netting and plastic sheeting.

Drying and environmental measurements were taken every two hours during the day until cherry was covered for the night. These measurements included date, time, atmospheric temperature (^{o}C), parchment temperature (^{o}C), ambient humidity (%), moisture content of cherry (%), density (g/lt.), weather condition (sunny, partly cloudy, cloudy, raining), if the parchment was covered (Y/N), if the parchment was turned (Y/N), and if the parchment depth on the drying bed was checked (Y/N).

Drying continued until the parchment reached a target moisture content of ≤11.5%. Once this threshold was achieved, parchment was transferred to clean polypropylene (PP) bags, labeled accordingly, and placed in a cool, protected storage area provided by the partner wet mill. Experimental lots were subsequently transported by project staff to the TNS office in Dilla for secure storage and further processing.

Green Analysis

Following the curing process (see *Cupping* section), each dried coffee sample was hulled at the TNS laboratory in Dilla to prepare for green coffee analysis. Two rounds of grading were conducted for each experimental lot.

In the first round, a portion of dried cherry from each lot was hulled and a 350g green coffee sample was weighed. Green bean defects were then identified and

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categorized in accordance with Specialty Coffee Association (SCA) green grading standards. Each defect category was weighed separately using a digital scale to quantify defect distribution. A second round of grading was then performed by hulling another portion of dried cherry from the same experimental lot. Again, 350g of green coffee was weighed, sorted, and analyzed using the SCA green grading protocol.

Conducting two independent grading rounds per trial lot allowed for more reliable estimation of defect prevalence and ensured greater analytical confidence in comparing green defect composition between stumped and unstumped samples.

Cupping

Following drying, all dried coffee cherry was rested (cured) for a minimum of four weeks to allow the internal moisture equilibrium within the beans to stabilize. This curing period is critical to ensuring proper flavor development and consistency during sensory analysis.

After resting, dried coffee pod from each lot was hulled, and samples were roasted in accordance with SCA arabica cupping standards at a partner cupping facility in Addis Ababa. Roasting was carried out using standardized protocols to minimize variation between samples. Two certified Arabica Q-Graders conducted the sensory evaluation over the course of two days.

Cupping began with a calibration session, during which five coffees of varying origin and processing method were evaluated and discussed among Q-graders to align sensory scoring and interpretation.

Experimental lots were then cupped in a blind and randomized format, grouped by processing site. For example, all samples from the lowland site were cupped together, with the order of stumped and unstumped samples randomized across the cupping tables. Once all samples from one site were completed, the process was repeated for the next processing site until all samples had been evaluated.

A second round of cupping was then conducted in the same randomized and blind format across all sites and following SCA standards. This second round of cupping was completed to increase robustness of results.

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Data Analysis

All data related to cherry deliveries, drying, green grading attributes and cupping evaluations were compiled and organized in Microsoft Excel. Datasets were cleaned and verified before undergoing statistical analysis. Given the study's objective was to compare physical and sensorial quality traits of stumped versus unstumped coffee, statistical comparisons were performed using paired *t*-tests in instances of equal sample size, or Welch's *t*-tests when sample sizes were not equal.

Prior to conducting any statistical tests, outliers within all datasets were identified and removed using the Interquartile Range (IQR) method. Both original and cleaned datasets were then analyzed using the appropriate *t*-tests, and results were compared to assess the impact of outlier removal on statistical outcomes. Whenever the removal of outliers did not significantly alter conclusions, results from the original datasets were preferred and reported, as they were deemed to better reflect real world conditions. Below, we go through the analysis performed for each dataset to describe in detail the methodologies used in this study.

<u>Cherry Delivery Data</u>

The composition of cherry deliveries between stumped and unstumped coffee trees were compared across several parameters including mass of ripe cherry, mass of hand-sorted reject (immature + overripe) cherry, mass of floaters, and total mass of reject cherry (immature + overripe + floaters). To make this comparison possible and standardize deliveries of varying volumes, all cherry delivery data were normalized to a reference weight of 100 kg.

Additionally, Brix (% sugar content) and the mass of 50 ripe cherries, each measure in 10 replicates for each trial lot, were analyzed to determine whether significant differences existed in sugar content and ripe fruit mass between stumped and unstumped trees.

All datasets were cleaned and two independent sets of analyses were run on the original and cleaned datasets to determine if significant differences existed.

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Drying Data

Environmental and processing data recorded during drying were compiled and factors suspected or known to impact cup quality were analyzed. These factors included the total drying time (hours), maximum bean temperature (◦C) recorded, and total time beans measured above 45 ◦C. These variables were compared between stumped and unstumped lots to assess whether drying conditions may have contributed to any observed differences in sensory quality.

Green Defect Data

The mass of green coffee defects were organized into three analytical categories including Human Independent, Huaman Biased, and Processing Defects. This distinction is important in better understanding the differences between stumped and unstumped coffee because we cannot completely remove the chance of introduced human bias within the study design. Therefore, we need to account for it in data analysis.

The Human Independent category included defects that occur independent of human intervention including insect-damaged beans, withered beans, and shells. These were analyzed to identify any inherent differences in physiological performance between stumped and unstumped coffee trees.

The Human Biased dataset expanded on the above by including black beans, sour beans, fungus-damaged beans, and immature beans. While these defects may occur naturally and reflect the inherent performance of the tree, they may also be influenced by human error. For example, the taller and wider canopy of an unstumped coffee tree may make harvesting more difficult or obscure ripe cherry from pickers thus increasing the likelihood of the development of sour beans. Although we cannot exclude human error as a cause of these defects, their presence could highlight the impact of biophysical differences between stumped and unstumped trees that that directly cause these defects and are important to analyze.

The Processing category comprised broken and cut beans, which occur during hulling of dried cherry pods. Differences in these defects were analyzed to assess

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whether stumped and unstumped coffee beans exhibited varying resistance to post-harvest handling practices.

Cupping Data

Cupping scores were first analyzed to assess consistency and potential biases between the two participating Q-Graders. Each cup attribute and total cup score were compared within each experimental site and treatment type (i.e. *stumped and unstumped*) using paired t-tests to identify any inherent biases of the cuppers that may have contributed to differences in the cupping results.

Following this, individual cup attributes (i.e. flavor, body, aftertaste, overall, etc.) and total cup scores were analyzed using *t*-tests to evaluate differences between stumped and unstumped coffees within each elevation category. This analysis aimed to determine if and where significant sensory differences between stumped and unstumped coffee sample existed across study sites.

Results

Given the breadth of analyses performed, results are presented in their respective categories below. Prior to analysis, all datasets underwent outlier detection, cleaning and comparison to original datasets. Importantly, these comparisons between cleaned and original datasets revealed no cases in any analyses where outlier removal altered the statistical significance of results. While outlier removal sometimes affected the strength of significance or reduced variance within a dataset, it did not change the overall outcome of any test.

In the results that follow, we prioritize reporting findings from the original datasets, in instances where cleaned data provided greater clarity, less variance or more conclusive outcomes, results from the cleaned datasets were reported.

Cherry Delivery and Ripeness Composition

Across all elevation zones, stumped coffee consistently produced a higher proportion of ripe cherry than unstumped coffee, though the drivers of these differences varied slightly by elevation.

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At the lowland site, stumped coffee cherry deliveries had a 13.00 % higher mean proportion of ripe cherry (M = 73.59, SD = 5.28) as compared to unstumped coffee (M = 65.12, SD = 8.41), $t(14) = 2.52$, $p = 0.02$. Additionally, the effect size (d = -1.19) was very large indicating a meaningful difference between the two (Figure 02). While the proportions of floaters and hand-sorted rejects did not differ significantly when analyzed independently, their combined total was significantly different between the stumped (M = 26.4, SD = 5.28) and unstumped cherry deliveries (M = 34.88, SD = 8.41), $t(14)$ = -2.52, $p = 0.02$, d = 1.19.

At the midland site, stumped coffee deliveries again showed a significantly higher mean proportion of ripe cherry (M = 67.03, SD = 8.25) compared to unstumped coffee (M = 57.21, SD = 6.23), $t(9) = 2.79$, $p = 0.02$ (Figure 02) with stumped deliveries exhibiting a 17.16% increase in ripe cherry over unstumped. Again, the effect size was strong (d = 0.88) indicating a strong divergence between the treatments. This difference however, was primarily driven by a 29.00 % reduction of hand-sorted rejects in stumped coffee samples (M = 23.89, SD =7.72) relative to unstumped samples (M = 33.65, SD = 6.60), $t(9)$ = -2.6, $p = 0.03$, d = -0.82.

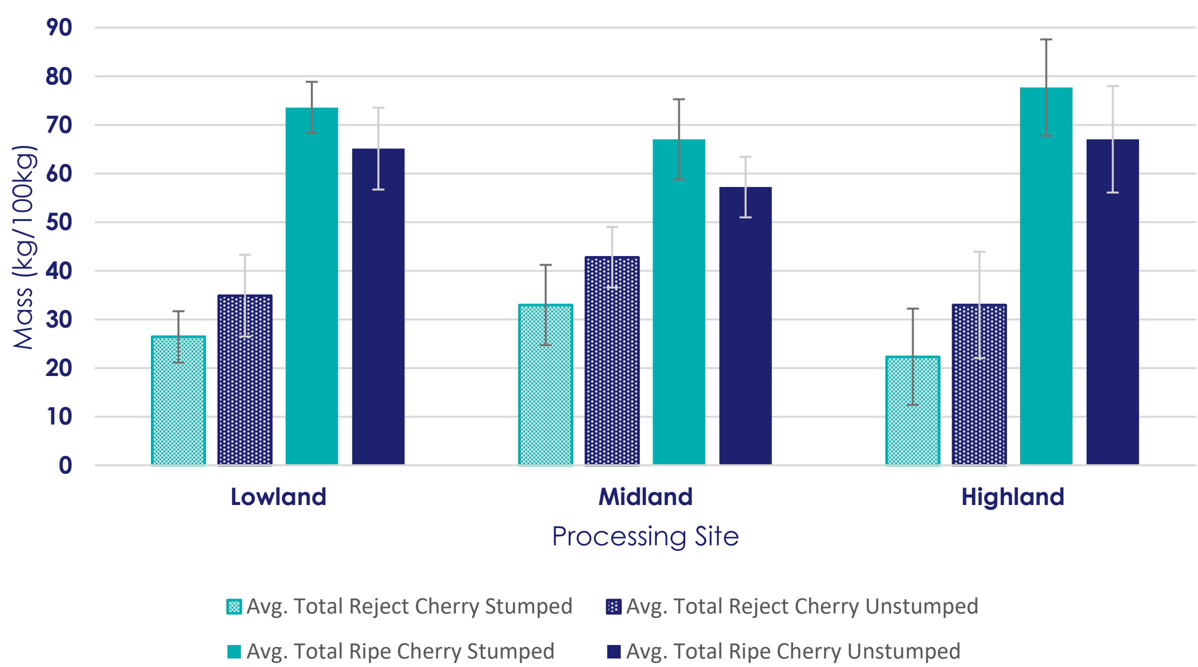

Figure 02. Composition of cherry deliveries at experimental coffee sites in Gedeo Zone, Ethiopia.

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At the highland site, this trend continued with stumped coffee cherry deliveries showing a significantly higher proportion of ripe cherry (M = 77.69, SD = 9.90) as compared to unstumped coffee (M = 67.04, SD =10.95), t(18) = 2.28, p = 0.03, d = -1.01 (Figure 02) which represented a 15.89 % increase in ripe cherry composition from unstumped deliveries. As at the other elevations, data suggests this to be a very meaningful result (d = -1.01) which was largely attributable to differences in the mean proportions of hand-sorted reject, which were significantly lower in stumped cherry deliveries (M = 16.51, SD = 8.89) than unstumped (M = 27.24, SD = 11.12) cherry deliveries, t(18) = -2.28, p = 0.03, d = 1.05 (see Appendix I).

Sugar Content and Cherry Mass

The average sugar concentrations of stumped and unstumped coffee did not differ significantly at the lowland or midland sites. However, at the highland site, unstumped coffee cherries had a significantly higher mean sugar concentration (M = 14.50, SD = 1.30) compared to stumped cherries (M = 14.04, SD = 1.66), t(166) = -2.11, p = 0.03. Despite this statistical significance, the effect size was small (d = 0.31), suggesting that the practical or agronomic relevance of this difference is limited (see Appendix II).

In terms of cherry mass, unstumped coffee cherries were significantly heavier at both the lowland and highland sites. At the lowland site, the mean mass of 50 ripe cherries from unstumped trees was 83.12 g (SD = 5.98), compared to 81.77 g (SD = 5.18) for stumped trees, t(80) = -2.51, p = 0.01, amounting to 1.65% increase in average cherry mass from stumped cherry. However, the effect size was small (d = -0.27, Figure 03). At the highland site, unstumped cherry mass averaged 87.41 g (SD = 4.99), while stumped cherry mass was significantly lower at 81.04 g (SD = 5.45), t(183) = -8.52, p < 0.001, meaning a 7.86% increase in mass over stumped cherry. Additionally, this result had a very large effect size (d = 1.22) (see Appendix II). While the effect size at the lowland site suggests only a modest difference, the highland site result indicates a substantial and meaningful difference in cherry mass between stumped and unstumped trees.

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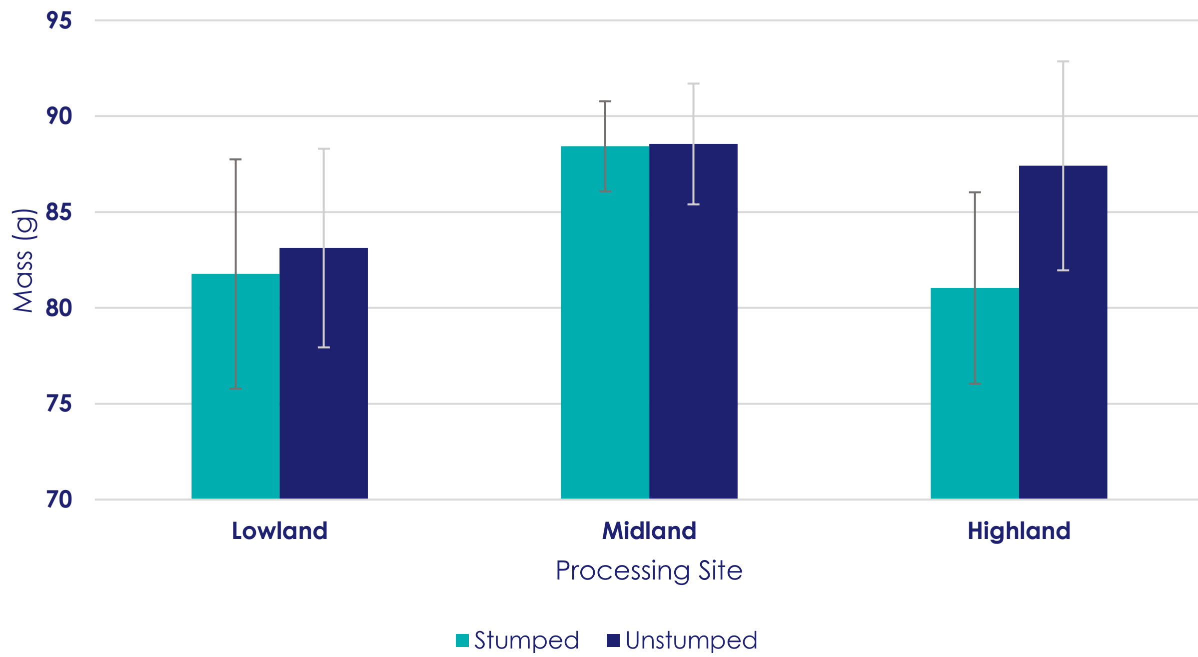

Figure 03. Comparison of cherry mass (g) measured at each experimental processing site in the Gedeo Zone, Ethiopia.

Drying Conditions

No significant differences were observed in total drying time between stumped and unstumped coffee at any of the three experimental processing sites. Additionally, there were no significant differences in maximum recorded bean temperature during drying or in the total duration of exposure to temperatures exceeding 45 °C (Table 01).

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Table 01. T-test results comparing attributes of coffee drying that could bias sensory (cupping) analyses comparing coffee samples from stumped and unstumped coffee trees across all experimental sites in the Gedeo Zone, Ethiopia.

<table>
<tr><th rowspan="2"></th><th rowspan="2" colspan="2"># Obs.</th><th colspan="2">Mean</th><th colspan="2">St. Dev.</th><th rowspan="2">df</th><th rowspan="2">t-stat.</th><th rowspan="2">P (0.05)</th><th colspan="2">CI (95%)</th><th rowspan="2">Effect Size</th></tr>
<tr><th>St.</th><th>Unst.</th><th>St.</th><th>Unst.</th><th>Lower</th><th>Upper</th></tr>
<tr><td colspan="13">Lowland Site</td></tr>
<tr><td>Total Drying Hours</td><td colspan="2">9</td><td>393.50</td><td>393.40</td><td>85.86</td><td>86.18</td><td>8</td><td>0.43</td><td>0.68</td><td>-0.49</td><td>0.71</td><td>0.14</td></tr>
<tr><td>Max Bean Temp (°C)</td><td colspan="2">9</td><td>45.28</td><td>44.49</td><td>4.52</td><td>3.61</td><td>8</td><td>0.91</td><td>0.39</td><td>-1.21</td><td>2.79</td><td>0.30</td></tr>
<tr><td>Hours above 45°C</td><td colspan="2">9</td><td>1.11</td><td>0.67</td><td>2.26</td><td>2.00</td><td>8</td><td>1.00</td><td>0.34</td><td>-0.58</td><td>1.47</td><td>0.33</td></tr>
<tr><td colspan="13">Midland Site</td></tr>
<tr><td>Total Drying Hours</td><td colspan="2">10</td><td>407.80</td><td>414.80</td><td>102.21</td><td>105.09</td><td>9</td><td>-1.41</td><td>0.19</td><td>-18.19</td><td>4.18</td><td>-0.44</td></tr>
<tr><td>Max Bean Temp (°C)</td><td colspan="2">10</td><td>48.27</td><td>48.72</td><td>3.37</td><td>2.44</td><td>9</td><td>0.67</td><td>0.67</td><td>-3.43</td><td>2.53</td><td>-0.15</td></tr>
<tr><td>Hours above 45°C</td><td colspan="2">10</td><td>13.00</td><td>15.20</td><td>9.20</td><td>9.85</td><td>9</td><td>-1.00</td><td>0.34</td><td>-7.18</td><td>2.78</td><td>-0.31</td></tr>
<tr><td colspan="13">Highland Site</td></tr>
<tr><td></td><td>St.</td><td>Unst.</td><td colspan="10"></td></tr>
<tr><td>Total Drying Hours</td><td>9</td><td>11</td><td>17.22</td><td>18.00</td><td>4.65</td><td>4.33</td><td>17</td><td>-0.38</td><td>0.71</td><td>-3.50</td><td>5.06</td><td>0.17</td></tr>
<tr><td>Max Bean Temp0 (°C)</td><td>9</td><td>11</td><td>42.66</td><td>41.91</td><td>4.71</td><td>3.48</td><td>14</td><td>0.40</td><td>0.69</td><td>-4.81</td><td>3.29</td><td>-0.18</td></tr>
<tr><td>Hours above 45°C</td><td>9</td><td>11</td><td>0.88</td><td>0.54</td><td>1.45</td><td>1.81</td><td>18</td><td>0.47</td><td>0.64</td><td>-1.87</td><td>1.19</td><td>-0.21</td></tr>
</table>

Green Defects (Human Independent)

Stumped coffee samples consistently demonstrated fewer human independent green coffee defects across all elevation zones. At the lowland site, severe insect damage was significantly lower in stumped samples (*M* = 1.24, *SD* = 0.68) compared to unstumped coffee (*M* = 2.13, *SD* = 0.48), $t(30) = -4.29$, $p < 0.001$, with a large effect size ($d = 1.46$) indicating a meaningful difference. Slight insect damage was also substantially reduced in stumped samples (M = 11.75, SD = 4.65) relative to unstumped samples (M = 19.88, SD = 7.53), $t(29) = -3.86$, $p < 0.001$, $d = 1.29$. Total insect damage (severe + slight) was decreased by 40.98 % observed from unstumped to stumped samples. Overall, the total mass of green defects was 36.17 % lower in significantly lower in stumped coffee (*M* = 16.52, *SD* = 8.26) compared to unstumped coffee (*M* = 25.88, *SD* = 10.02), $t(32) = -3.02$, $p < 0.001$, with a very large effect size ($d = 1.01$)

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suggesting stumping had a meaningful impact on the human independent defects found within coffee samples (Figure 04).

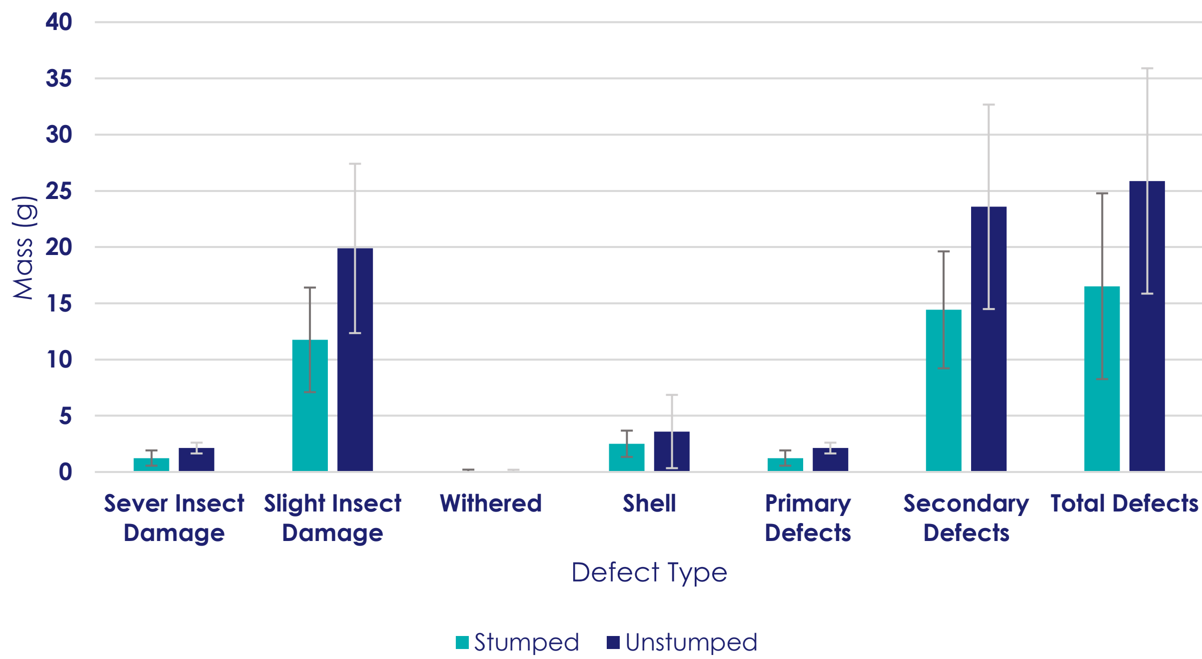

Figure 04. Mass (g) of green bean defects (no human bias) within 350g samples from stumped and unstumped coffee trees at the lowland experimental site in Dilla, Gedeo, Ethiopia.

At the midland site, stumped samples again had significantly fewer severe insect defects (M = 0.64, SD = 0.43) than unstumped samples (M = 1.02, SD = 0.56), $t(19)$ = -2.4, p = 0.02, d = -0.54. Stumped coffee also exhibited fewer withered beans (M = 0.01, SD = 0.03) compared to unstumped coffee (M = 0.07, SD = 0.08), $t(19)$ = -3.68, $p < 0.001$, d = -0.82 (Figure 05) with the effect sizes of both indicating modest significance or magnitude of these observed differences. The average mass of other defects and total defects at the midland were less in stumped coffee samples but these results did not prove significant due to high variance.

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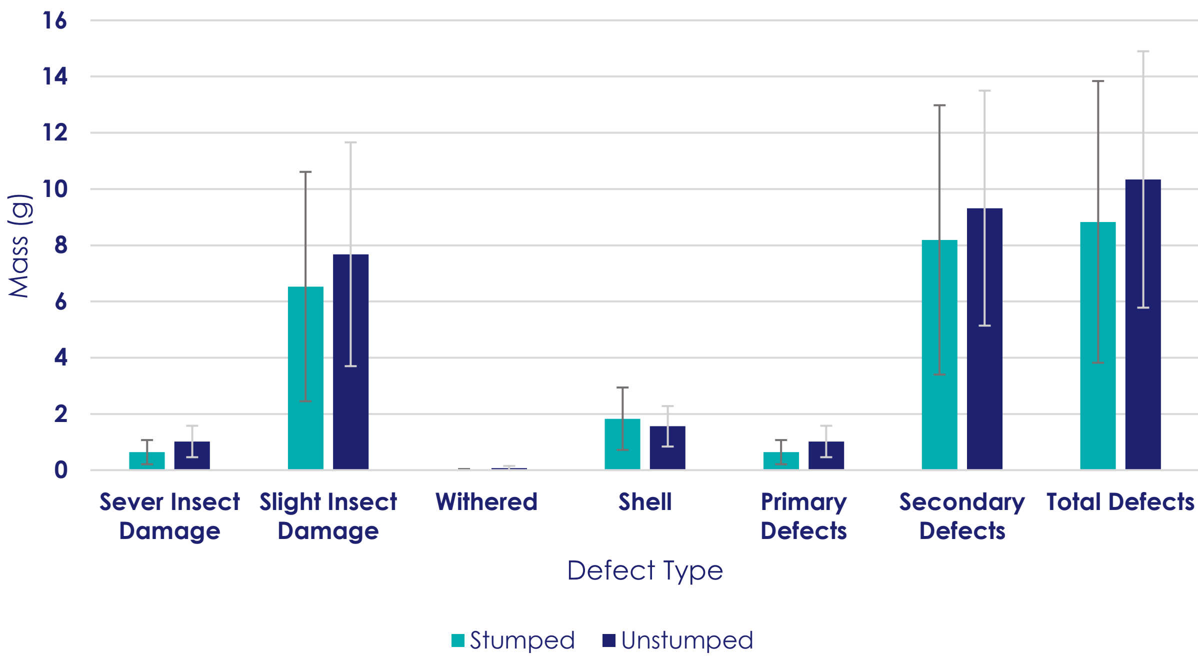

Figure 05. Mass (g) of green bean defects (no human bias) within 350g samples from stumped and unstumped coffee trees at the midland experimental site in Wonago, Gedeo, Ethiopia.

At the highland site, stumped coffee samples exhibited significantly lower levels of both severe and slight insect damage compared to unstumped samples. The mass of severe insect damage was lower in stumped coffee ($M = 0.07$, $SD = 0.09$) than in unstumped coffee ($M = 0.42$, $SD = 0.40$), $t(24) = -3.92$, $p < 0.001$, with a moderate effect size ($d = 0.46$). Similarly, slight insect damage was lower in stumped samples ($M = 1.71$, $SD = 0.85$) relative to unstumped ($M = 3.63$, $SD = 2.12$), $t(29) = -3.87$, $p < 0.001$, $d = 0.48$. In total, insect related defect occurrences were reduced by 56.05 % when comparing unstumped to stumped samples. In addition, the total mass of secondary defects were significantly lower in stumped coffee ($M = 2.61$, $SD = 1.44$) compared to unstumped coffee ($M = 4.47$, $SD = 1.44$), $t(36) = -3.11$, $p < 0.001$, $d = 0.52$ (Figure 06; Appendix III). While all comparisons were statistically significant, the effect sizes suggest that the magnitude of these differences was modest.

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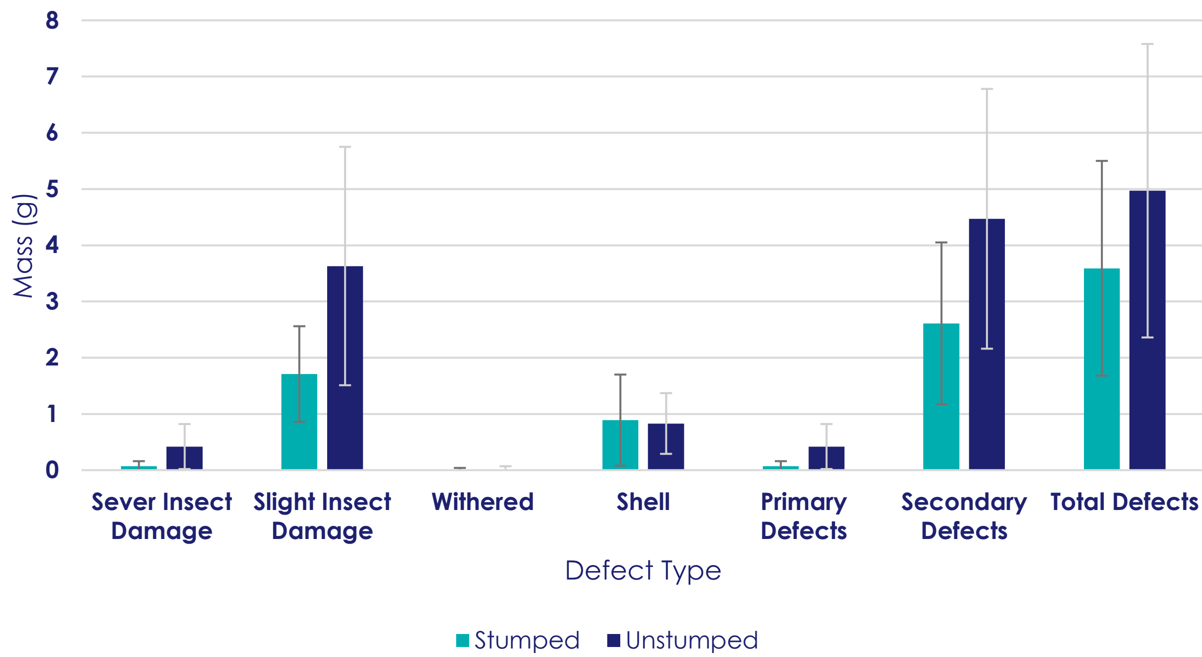

Figure 06. Mass (g) of green bean defects (no human bias) within 350g samples from stumped and unstumped coffee trees at the highland experimental site in Dumerso, Gedeo, Ethiopia.

Green Defects (Human Bias)

At the lowland site, stumped coffee samples exhibited significantly lower masses of several green coffee defects as compared to unstumped samples. Severe insect damage was substantially lower in stumped coffee (*M* = 1.24, *SD* = 0.68) than in unstumped samples (*M* = 2.13, *SD* = 0.48), $t(30) = -4.29$, $p < 0.001$, with a very large effect size ($d = 1.46$). Primary defect mass was also significantly lower in stumped samples (*M* = 1.19, *SD* = 0.62) as compared to unstumped coffee (*M* = 2.43, *SD* = 1.16), $t(17) = -4.45$, $p < 0.001$, $d = 1.08$, indicating a large and meaningful reduction in primary defect mass.

Partial sour beans were less prevalent in stumped coffee (*M* = 0.11, *SD* = 0.12) than in unstumped samples (*M* = 0.20, *SD* = 0.12), $t(31) = -2.10$, $p = 0.04$, $d = 0.72$, reflecting a moderate effect size. Slight insect damage was also significantly reduced in stumped coffee (*M* = 11.75, *SD* = 4.65) relative to unstumped coffee (*M* = 19.88, *SD* = 7.53), $t(29) = -3.86$, $p < 0.001$, with a large effect size ($d = 1.29$). Similarly, secondary defects were significantly lower in stumped samples (*M* = 14.55, *SD* = 5.21) than in unstumped samples (*M* = 24.16, *SD* = 9.20), $t(27) = -3.82$, $p < 0.001$, $d = 1.27$. Total green

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defect mass followed the same pattern, and overall there was a 34.78 % reduction in defect mass in stumped coffee samples (*M* = 17.46, *SD* = 8.67), showing a markedly lower overall defect mass, as compared to unstumped coffee samples (*M* = 26.7, *SD* = 10.23), *t*(27) = -3.10, *p* 0.006, with a large effect size (*d* = 0.73). These large effect sizes across primary, secondary, and total defects suggest that the differences observed between stumped and unstumped coffee are not only statistically significant, but also highly relevant (Figure 07, Appendix IV).

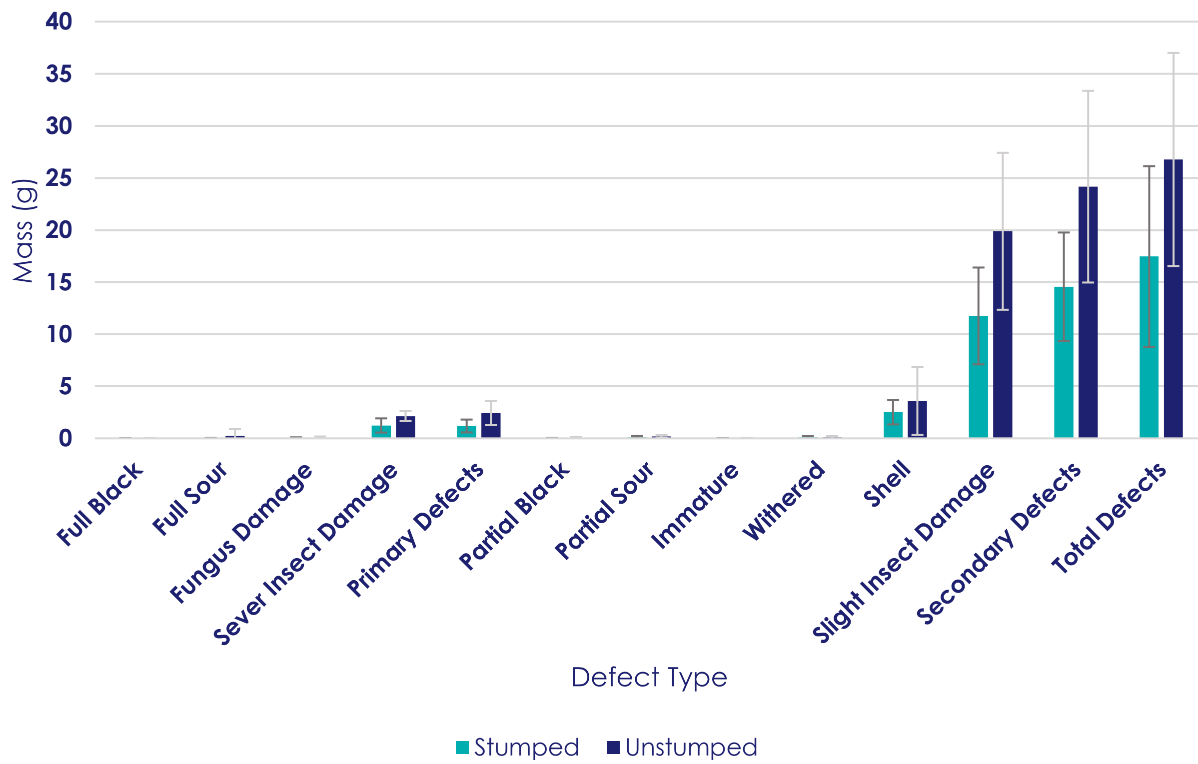

Figure 07. Mass (g) of green bean defects (potential human bias) within 350g samples from stumped and unstumped coffee trees at the lowland experimental site in Dilla, Gedeo, Ethiopia.

At the midland site, stumped coffee samples again exhibited significantly reduced amounts of several green coffee defects compared to unstumped samples. The mass of severe insect damage was lower in stumped coffee (*M* = 0.78, *SD* = 0.07) than in unstumped samples (*M* = 1.13, *SD* = 0.05), *t*(21) = -3.41, $p < 0.001$, with a very large effect size (*d* = 1.39), indicating a substantial difference in severe pest damage. Primary defect mass was also significantly reduced in stumped samples (*M* = 0.78, *SD* =

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0.26) compared to unstumped coffee (*M* = 1.26, *SD* = 0.22), *t*(10) = -4.15, *p* < 0.001, with the effect size (*d* = 1.25) suggesting a strong and meaningful reduction. The mass of withered beans was significantly lower in stumped coffee samples (*M* = 0.001, *SD* = 0.03) than unstumped coffee samples (*M* = 0.07, *SD* = 0.08), *t*(19) = -3.68, *p* < 0.001, with a large effect size (*d* = 0.82). Together, these results indicate a consistent and substantial reduction in several defects in stumped coffee at the midland site (Figure 08; Appendix V).

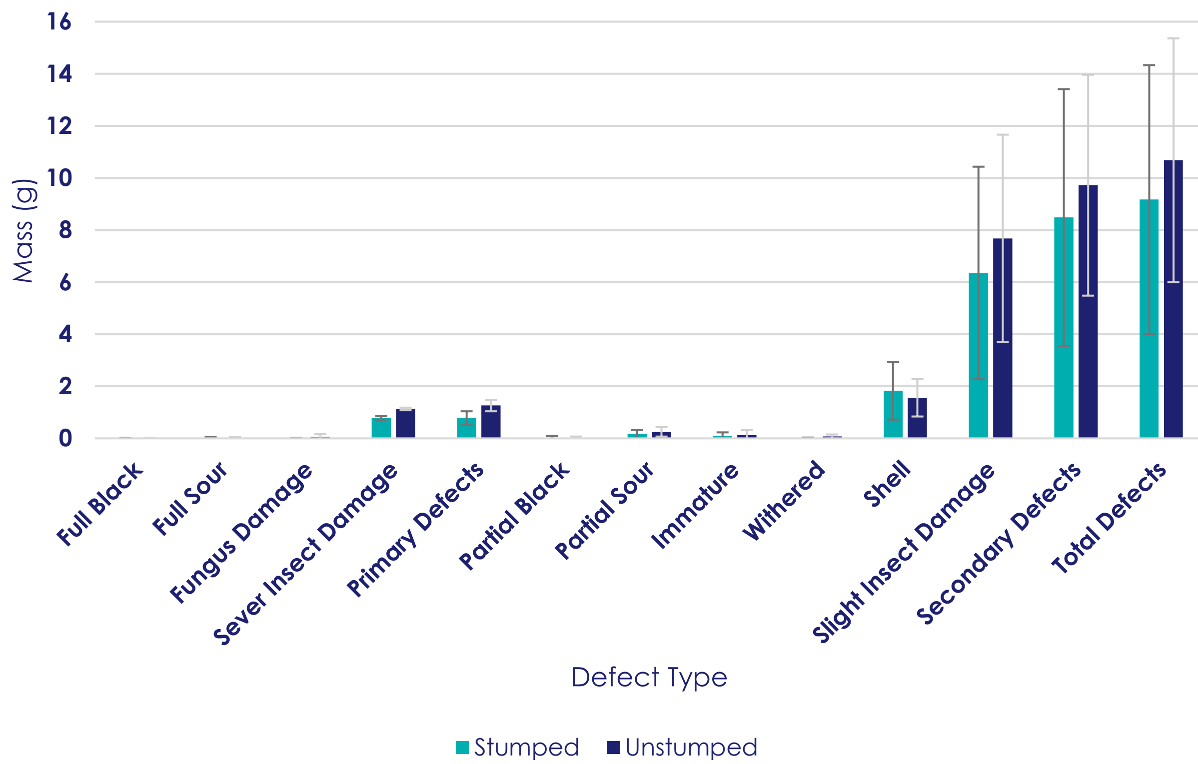

Figure 08. Mass (g) of green bean defects (potential human bias) within 350g samples from stumped and unstumped coffee trees at the midland experimental site in Wonago, Gedeo, Ethiopia.

At the highland site, full black beans were entirely absent in stumped coffee (*M* = 0.00, *SD* = 0.00) but present in unstumped samples (*M* = 0.02, *SD* = 0.05), *t*(21) = -2.32, *p* = 0.03, with a small-to-moderate effect size (*d* = 0.49). Fungus-damaged beans followed a similar pattern, being absent in stumped samples (*M* = 0.00, *SD* = 0.00) but present in unstumped coffee (*M* = 0.03, *SD* = 0.07), *t*(21) = -2.16, *p* = 0.04, *d* = 0.49. The mass of

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severe insect damage was significantly lower in stumped samples (*M* = 0.07, *SD* = 0.09) compared to unstumped samples (*M* = 0.42, *SD* = 0.40), $t(24) = -3.92$, $p < 0.001$, $d = 0.46$. Slight insect damage was also reduced in stumped coffee (*M* = 1.71, *SD* = 0.85) relative to unstumped (*M* = 3.63, *SD* = 2.21), $t(29) = -3.87$, $p < 0.001$, with a small-to-moderate effect size ($d = 0.48$).

For broader defect categories, stumped coffee samples had significantly lower primary defect mass (*M* = 0.09, *SD* = 0.09) than unstumped coffee samples (*M* = 0.49, *SD* = 0.43), $t(23) = -4.23$, $p < 0.001$, $d = 0.46$. The mass of secondary defects were also lower in stumped samples (*M* = 2.77, *SD* = 1.49) compared to unstumped samples (*M* = 4.60, *SD* = 2.29), $t(36) = -3.21$, $p < 0.001$, $d = 0.50$. Overall, total green defect mass was significantly lower in stumped coffee (*M* = 3.60, *SD* = 1.89) than in unstumped coffee (*M* = 5.19, *SD* = 2.60), $t(38) = -2.23$, $p = 0.03$, with a moderate effect size ($d = 0.52$). This represents a reduction of 30.63 % from stumped to unstumped coffee samples. While these differences were consistently statistically significant, the associated effect sizes suggest that the magnitude of differences was moderate (Figure 09, Appendix VI).

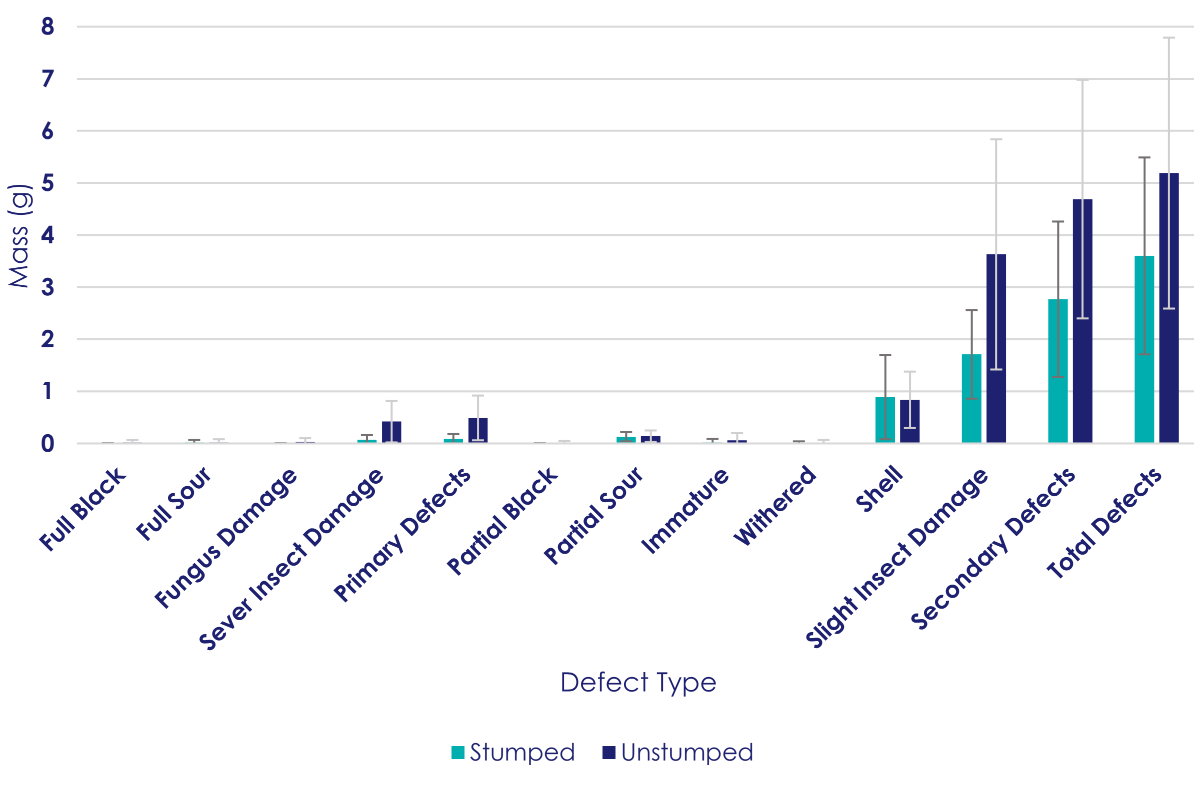

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Figure 09. Mass (g) of green bean defects (potential human bias) within 350g samples from stumped and unstumped coffee trees at the highland experimental site in Dumerso, Gedeo, Ethiopia.

Green Defects (Processing)

Processing defects, assessed by the occurrence of broken and cut beans, varied across sites. At the lowland site, stumped coffee samples exhibited significantly fewer broken beans (*M* = 3.59, *SD* = 1.32) than unstumped samples (M = 5.26, SD = 2.33), *t*(28) = -2.58, *p* = 0.01. This represents a 31.75 % reduction in the occurrence of broken beans with an large effect size (Cohen's *d* = 0.86), indicating a meaningful difference between the two treatments. At the midland site, the trend was even more pronounced. Stumped coffee (*M* = 2.25, *SD* = 1.18) had significantly fewer broken and cut beans than unstumped coffee (*M* = 4.20, *SD* = 2.62), *t*(19) = -4.7, *p* < 0.001. This represented a 46.43 % reduction and the effect size was again large (Cohen's *d* = 1.05), suggesting a strong impact of stumping on resistance to post-harvest mechanical damage. In contrast, at the highland site, no significant difference was found between stumped (*M* = 0.82, *SD* = 0.34) and unstumped (*M* = 0.73, *SD* = 0.22) samples, *t*(32) = 0.5, *p* = 0.62 (Table 02, Figure 10).

Table 02. T-test results comparing the mass (g) of broken/cut bean defects per 350g samples from stumped and unstumped coffee trees at all experimental sites in Gedeo, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
	St.	Unst.	*St.*	*Unst.*	*St.*	*Unst.*				Lower	Upper	
Lowland Site Broken/Cut	15	18	3.59	5.26	1.32	2.33	28	-2.58	0.01	0.34	2.99	0.86
Midland Site Broken/Cut		20	2.25	4.20	1.18	2.62	19	-4.7	0.00	-2.82	-1.08	-1.05
Highland Site Broken/Cut	18	22	0.82	0.73	0.34	0.22	32	0.50	0.62	-1.59	12.85	0.52

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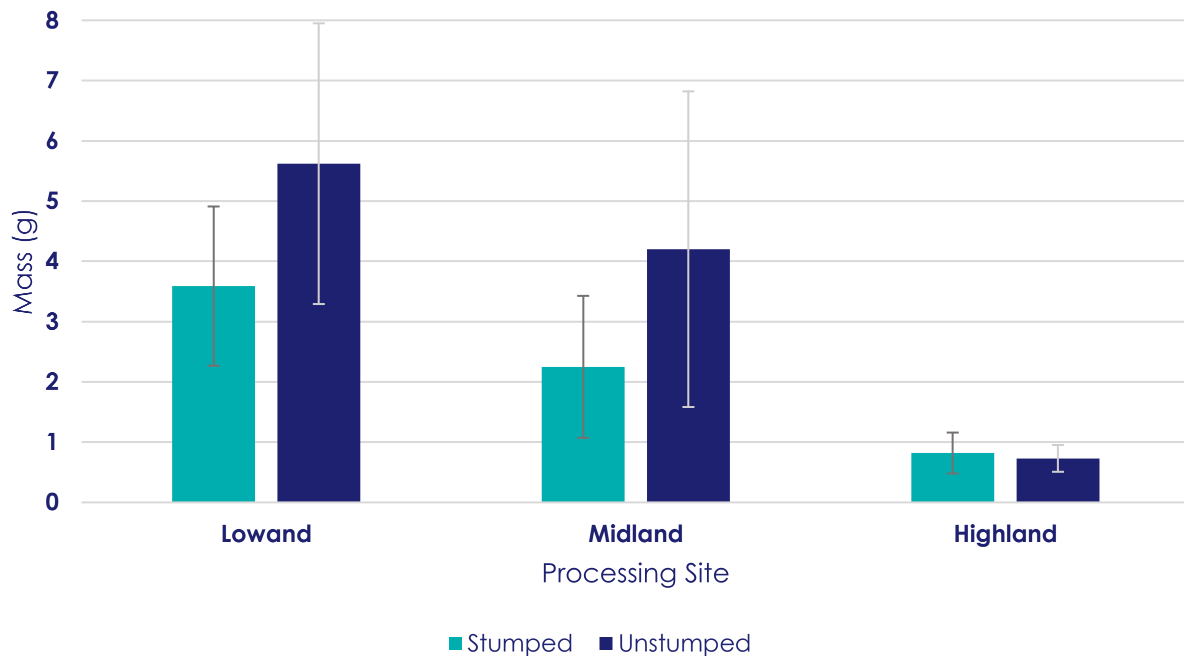

Figure 10. Mass (g) of broken bean defects stumped and unstumped coffee measured from coffee samples across all experimental sites in Gedeo Zone, Ethiopia.

Bean Size and Density

Across all experimental sites, no significant differences were observed in bean density between stumped and unstumped coffee samples (see Appendix II). Significant differences were found in bean size however, particularly in the mass of coffee below screen-14, which was consistently higher in unstumped samples. At the lowland site, the mass of beans passing through screen-14 was significantly lower in stumped coffee (M = 19.11, SD = 6.48) compared to unstumped coffee (M = 25.20, SD = 8.48), $t(17) = -2.98$, $p < 0.001$, $d = -0.70$, indicating a moderate effect size. The total difference between stumped and unstumped was 6.09 g representing a 24.17 % reduction. At the midland site, a similar pattern was observed, with stumped coffee samples (M = 12.62, SD = 2.27) exhibiting on average 7.20 g (36.33 %) less below screen-14 mass than unstumped coffee samples (M = 19.82, SD = 4.02), $t(20) = -6.43$, $p < 0.001$. The effect size ($d = -1.44$) suggests a very large a very meaningful difference. At the highland site, unstumped coffee (M = 19.71, SD = 3.54) samples had significantly more under screen coffee than stumped coffee (M = 14.34, SD = 2.82) samples, $t(38) = -5.33$, $p < 0.001$. On average the difference was 5.37 g which represented a 27.25 %

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reduction in broken bean mass. Moreover the effect size (*d* = -1.65) suggested a very significant difference between stumped and unstumped (Figure 11, Appendix II).

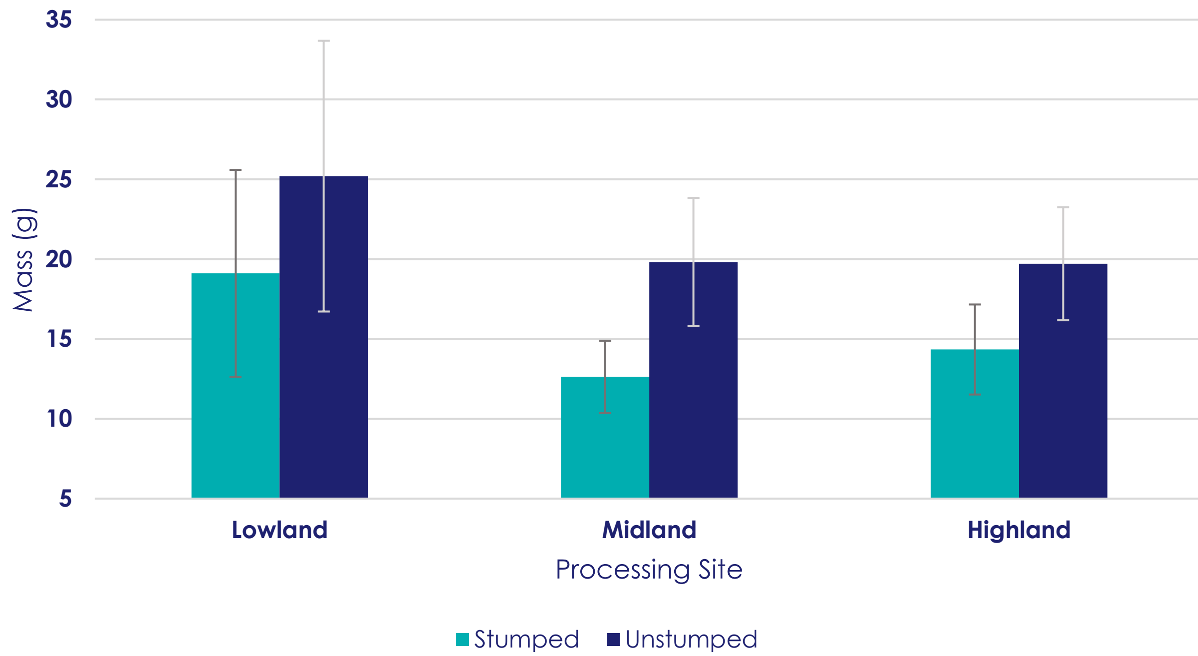

Figure 11. Mass (g) of under screen (14) coffee of stumped and unstumped coffee measured from coffee samples across all experimental sites in Gedeo Zone, Ethiopia.

Cupper Bias Analysis

Coffee cup and attribute scores were compared between Q-graders, referenced as Cupper A and Cupper B, in the results below. For stumped coffees at the lowland site, Cupper A reported significantly higher scores for Fragrance/Aroma (M = 7.71, SD = 0.23) than Cupper B (M = 7.54, SD = 0.21), $t(17)$ = 3.12, p = 0.01, d = 0.73, reflecting a moderate-to-large effect size. Flavor scores were also significantly higher (M = 7.64, SD = 0.18 vs. M = 7.53, SD = 0.21), $t(17)$ = 2.41, p = 0.03, d = 0.57, indicating a moderate effect. Total cup score was similarly elevated in Cupper A's evaluation (M = 83.76, SD = 1.21 vs. M = 83.33, SD = 1.10), $t(17)$ = 3.02, p = 0.01, d = 0.71, also indicating a moderate-to-large difference. All other lowland attributes, including Acidity and Aftertaste, showed no significant differences.

At the midland site, Cupper A scored Acidity significantly lower than Cupper B (M = 7.63, SD = 0.26 vs. M = 7.76, SD = 0.25), $t(19)$ = –2.34, p = 0.03, d = -0.52, indicating a

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moderate difference in perception. In contrast, Cupper A gave higher scores for Body (M = 7.73, SD = 0.16 vs. M = 7.58, SD = 0.23), $t(19) = 3.94$, $p < 0.001$, $d = 0.88$, and Aftertaste (M = 7.60, SD = 0.21 vs. M = 7.43, SD = 0.26), $t(19) = 3.62$, $p = 0.002$, $d = 0.81$, both reflecting large effect sizes. Other midland attributes, including Flavor and Cup Score, were not significantly different.

In the highland site, no significant differences were observed between Cupper A and Cupper B for any evaluated attributes or total cup score. Across all three sites, Sweetness, Uniformity, and Clean Cup were uniformly rated at 10.0 by both cuppers, resulting in no variance (see Appendix VII).

For unstumped coffees, fewer differences were observed. In the lowland site, none of the evaluated attributes differed significantly between Cupper A and Cupper B. At the midland site, Flavor was the only attribute with a significant difference (M = 7.33, SD = 0.23 vs. M = 7.20, SD = 0.35), $t(19) = 2.36$, $p = 0.03$, $d = 0.53$, which corresponds to a moderate effect size. In the highland site, Cupper A scored Body higher (*M* = 7.51, SD = 0.12) than Cupper B (M = 7.36, SD = 0.32), $t(21) = 2.14$, $p = 0.04$, $d = 0.46$, again suggesting a modest difference. All other highland cup attributes for stumped coffee were not significantly different (Appendix VIII).

Cupping Results

Across all three sites for all cupping attributes, stumped coffee samples were scored significantly higher than unstumped coffee samples (Appendix IX) by Q-graders participating in the study (Figure 12, 13, 14). Moreover, both Q-graders noted that the terroir and origin-specific flavor characteristics of the stumped coffees were more pronounced and expressive in the cup. In contrast, the flavor profiles of unstumped coffees were described as muted, with less clarity in representing the distinctiveness of place.

Overall, significant differences in total cup scores between stumped and unstumped samples were observed. At the lowland site, average cup score difference was 2.36 points with stumped coffee (*M* = 83.55, *SD* = 1.16) scoring higher than unstumped coffee (*M* = 81.18, SD =1.31) samples, $t(35) = 9.78$, p = < 0.001, $d = 1.63$. At

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the midland site, stumped coffee (*M* = 83.29, *SD* = 1.21) cupped on average 1.65 points higher than unstumped (*M* = 81.64, *SD* = 1.57) coffee, *t*(39) = 6.06, *p* = < 0.001, *d* = 0.96. The biggest difference in total cup score however, was seen at the highland site where stumped coffee (*M* = 85.09, *SD* = 0.71) coffee scored an average of 3.26 points higher than unstumped coffee (*M* = 81.83, *SD* = 1.58), *t*(62) = 12.24, p = < 0.001, *d* = -2.57 (Figure 15).

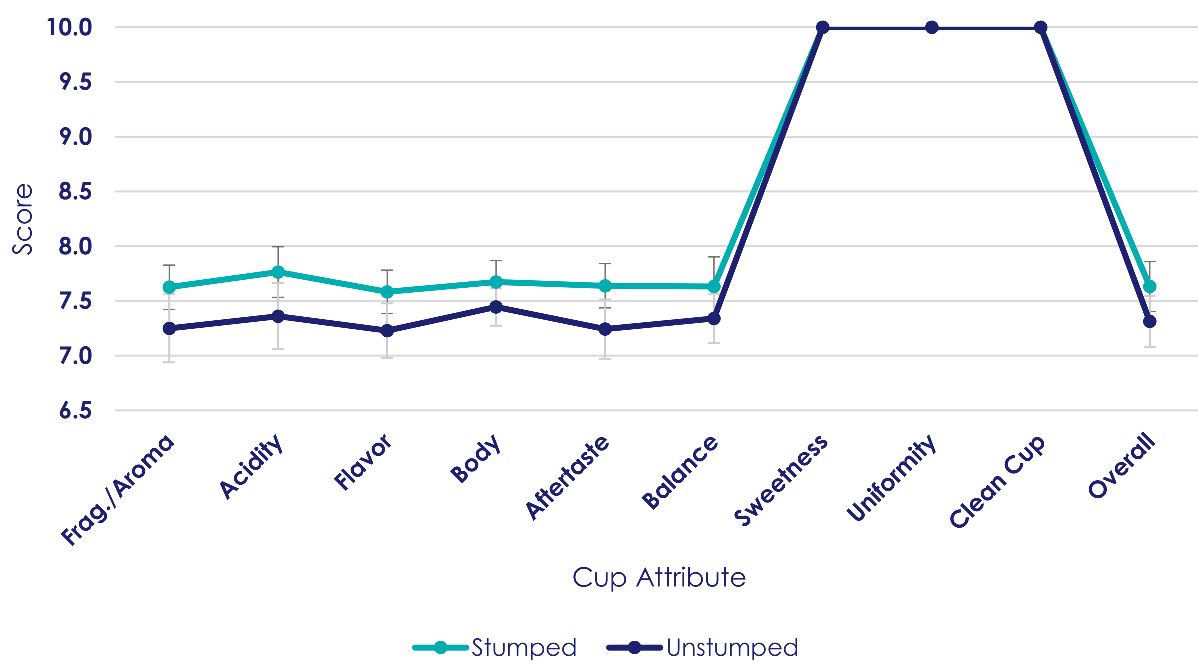

Figure 12. Cup attribute scores of stumped and unstumped coffee processed at the lowland experimental site in Dilla, Gedeo, Ethiopia.

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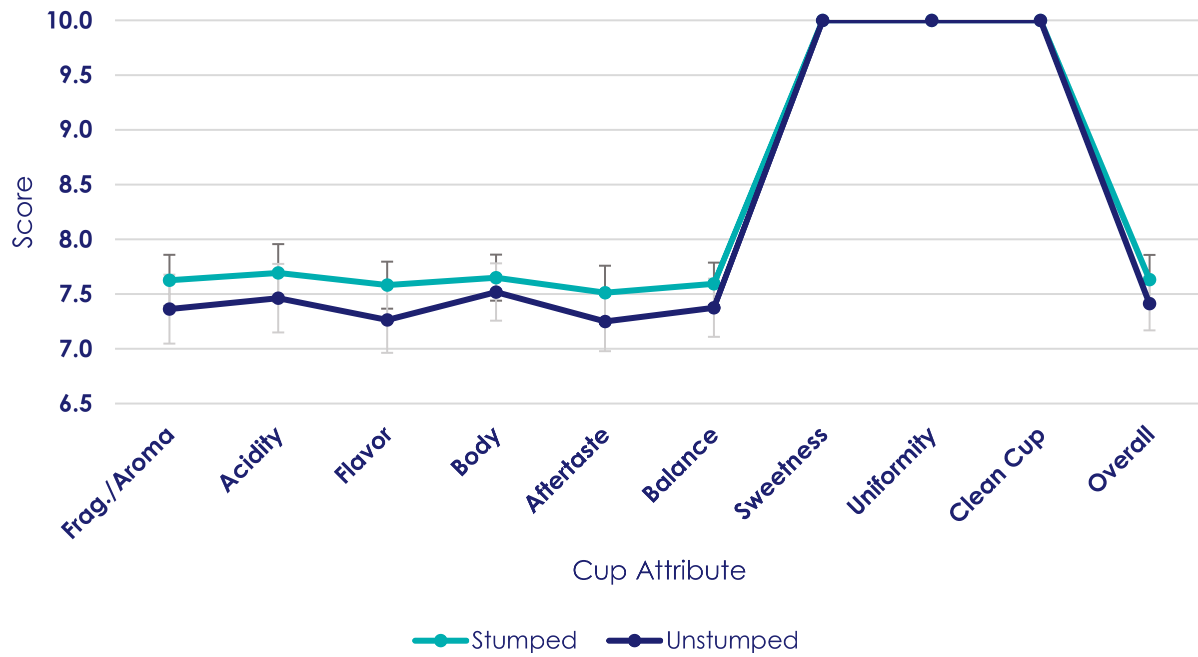

Figure 13. Cup attribute scores of stumped and unstumped coffee processed at the midland experimental site in Wonago, Gedeo, Ethiopia.

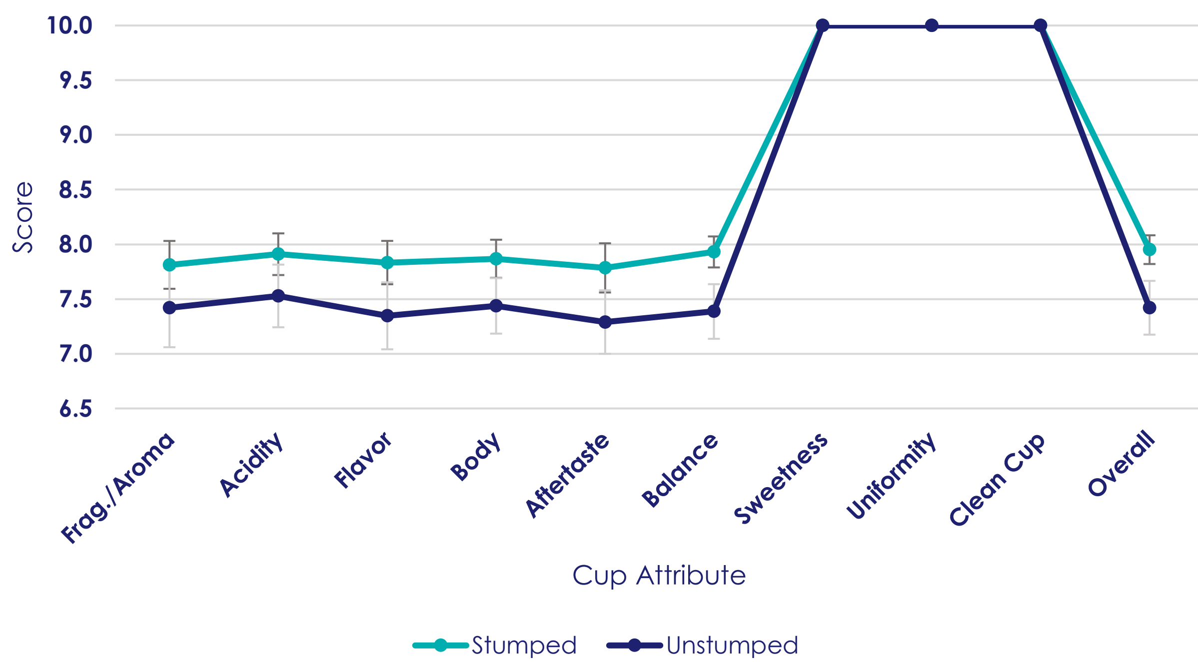

Figure 14. Cup attribute scores of stumped and unstumped coffee processed at the highland experimental site in Dumerso, Gedeo, Ethiopia.

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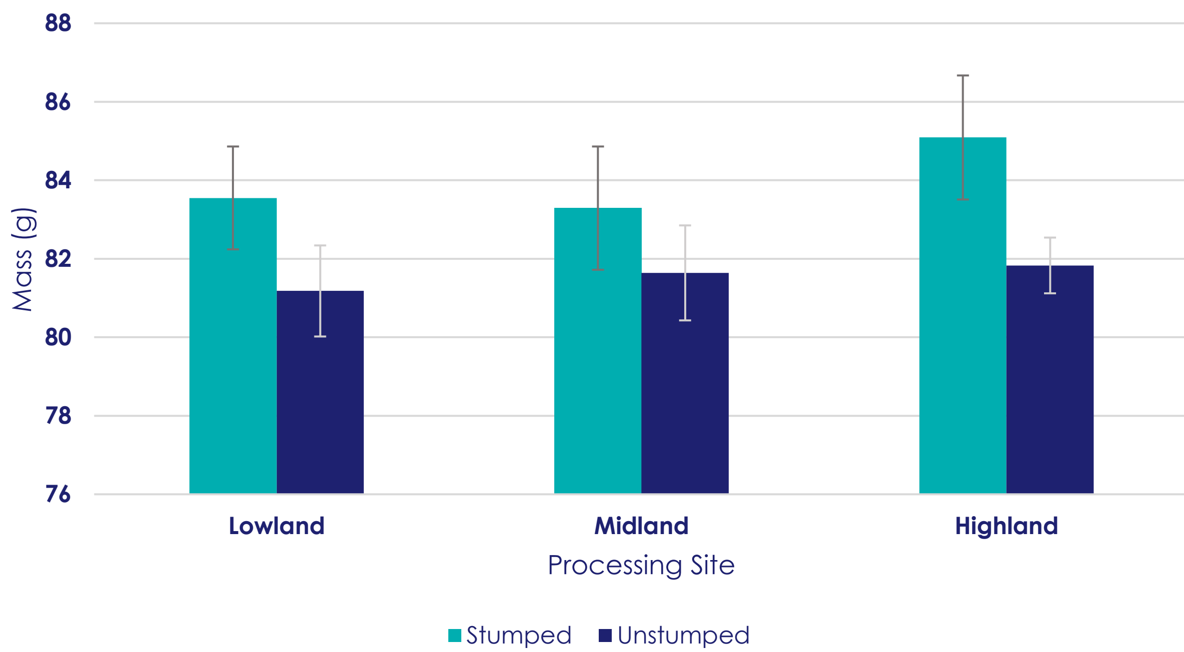

Figure 15. Comparison of cup scores between stumped and unstumped coffee samples across all experimental sites in Gedeo Zone, Ethiopia.

Discussion

The findings of this study highlight numerous benefits associated with rejuvenating older coffee trees through stumping. Across lowland, midland, and highland sites, there were marked differences and benefits from cherry deliveries and bean size, to cup scores. These differences will be discussed in detail in their respective sections below.

Cherry Delivery and Ripeness Composition

Across all elevation zones, cherry deliveries from stumped coffee trees had consistently higher proportions of ripe cherry as compared to unstumped coffee trees see Appendix X). Additionally, the magnitude of this pattern was pronounced with large effect sizes meaning that the magnitude of these differences was significant. On average, ripe cherry composition increased by 15.3% across all sites (Table 03), which would significantly improve both processing efficiency and coffee quality.

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Two plausible explanations might account for these differences include, 1.) more synchronized and/or uniform ripening, possibly due to rejuvenated canopy structure and improved nutrient distribution among fruiting branches; or 2.) the physical structure of the stumped canopies could be easier for harvesters to work and spot ripe cherry within. This would reduce the chance of knocking immature cherry and missing ripe cherry thereby leading to over ripen cherry. It could also be a combination of these scenarios at play.

Though the exact mechanisms remain uncertain, the clear improvement observed in cherry composition strongly supports promoting stumping as an effective agronomic practice to improve cherry compositions. To fully understand the underlying causes of improved ripeness, future studies should closely examine cherry ripening patterns and harvesting behaviors in stumped versus unstumped coffee plots. Regardless, our findings suggest that coffee farmers and producers can directly benefit by adopting and promoting coffee rejuvenation, leading to higher-quality cherry deliveries and potentially higher profitability.

Sugar Content and Cherry Mass

Differences in sugar content (Brix) between stumped and unstumped coffee cherries were minimal across all elevations, with only a slight effect observed at the highland site. This suggests that stumping does not significantly impact sugar accumulation within the coffee cherries themselves.

In contrast, notable differences in cherry mass were observed, particularly at the lowland and highland sites, where unstumped cherries were significantly heavier than those from stumped trees (see Appendix X). Interestingly, this increase in fruit mass did not correspond with larger beans. On average, stumped coffee produced larger beans, as indicated by a consistently lower proportion of beans below screen-14 across all sites (Table 03). This finding reveals a clear decoupling between total fruit mass and bean size.

Together, these data suggest that stumping modifies the source-sink relationships within the coffee tree. By rejuvenating the leaf canopy and enhancing nutrient flow,

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stumped trees achieve a higher leaf-area-to-fruit ratio. This improved ratio likely ensures better carbohydrate and nutrient supply to developing seeds, resulting in leaner cherries (reduced mesocarp weight) but larger, better-developed beans. Conversely, heavier cherries from unstumped trees may reflect continued expansion of less demanding mesocarp tissues. In these older trees, limited vascular conductivity and greater competition among numerous sinks may constrain nutrient delivery during the critical bean-filling phase.

These observations align with findings from similar pruning and fruit-load management studies in coffee and other perennial crops, which consistently report reduced fruit mass alongside increases in bean or kernel size when sink density is lowered (Cannell 1985; Vaast et al. 2006). Furthermore, anatomical studies indicate that newly formed xylem and phloem tissues on rejuvenated branches transport sugars more efficiently than older tissues, thus supporting optimal seed development (Soares et al. 2021, Wintgens 2012).

This has significant implications for producers and especially those purchasing cherry for processing. By promoting stumping producers can increase the turnout of cherry to green coffee by reducing the 'water weight' within the cherry they purchase. On average, across all sites there was a 3 % increase in cherry mass from stumped to unstumped deliveries (Table 03). This increase, however, did not correlate with larger or more quality beans and represents lost weight and profits. Although 3% sounds small, at volume it becomes significant especially considering that the coffee turnout ratio is 6:1 cherry to green coffee, which compounds the negative impact of water weight at time of cherry purchase. Our results suggest that rejuvenating coffee trees can reduce these losses, and it is recommended that farmers and managers promote rejuvenation to increase their turnouts and reduce profit loss associated with poor cherry purchases.

Drying Conditions

No differences in drying duration or heat exposure were observed between treatments. This confirms that post-harvest processing conditions were controlled effectively and do not explain the observed differences in physical or sensory attributes.

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The absence of drying-related variation strengthens the case that tree-level physiology and not drying bias, explains the quality differences observed.

Green Defects (Human Independent)

Results clearly indicate that stumping reduces green coffee defects inherent to coffee trees, those defects occurring independently of human actions. Across all elevation bands, stumped coffee samples showed notably lower incidences of insect damage and withered beans. The reductions were particularly pronounced at lowland sites, where pest pressure is greatest (see Appendix X). Here, severe insect damage decreased by 41.78 %, slight insect damage by 40.89 %, and total defect mass fell by 36.17 %. At the midland site, defect reductions remained significant but were more modest. In the highlands, stumping substantially reduced severe insect damage and cut overall secondary defects by 41.61 %, although the effect sizes were moderate due to already lower defect masses at higher elevations.

According to results, stumping reduced the presence of defects that occur independently of human interference. Stumped coffee samples had markedly lowered insect and withered defects across all altitude bands. At lowland sites, where pest pressure is highest, severe and slight insect damage fell by 41.78 % and 40.89 %, respectively, and total defect mass dropped by 36.17 %. At midland sites the reductions remained significant but more modest, while in the highland site stumping greatly reduced severe insect damage and cut overall secondary defects by 41.61 %, although effect sizes were moderate. These moderate effects were likely a result of overall reduced defect masses at the midland and highland sites.

Most defects observed were related to insect damage, aligning well with the known temperature-dependent prevalence of coffee berry borer (*Hypothenemus hampei*) and related pests, which naturally decline at higher elevations. Consequently, the largest defect reductions observed at lowland sites support existing knowledge about pest distributions.

In relation to this, two complimentary mechanisms likely explain for this these observed reductions. First, stumping removes infested wood and berries and opens the

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canopy, practices already recommended in integrated pest-management guidelines as a means of suppressing coffee berry borer populations. Second, rejuvenated trees benefiting from improved leaf-area-to-fruit ratios and nutrient distribution, produce cherries with stronger constitutive defenses. This results in cherries that are less susceptible to borer entry and subsequent defects.

Overall, the average decrease in human-independent green defects was 29.9% across all sites (Table 03), highlighting a significant improvement attributable directly to the biophysical advantages of rejuvenated coffee trees. Because stumped and unstumped trees were interspersed closely within farm plots, insect distribution biases were minimized. Furthermore, careful controls implemented during processing effectively ruled out other potential sources of bias. Therefore, the observed reductions in defects are strongly linked to the physiological differences resulting from stumping.

Given these findings, coffee farmers and managers are strongly recommended to adopt rejuvenation pruning as a practical measure for reducing inherent coffee defects, especially in regions with elevated pest pressure.

Green defects (Human Biased)

Certain green coffee defects can result from human error or processing biases, making them challenging to attribute solely to tree physiology. In this study design, it was impossible to completely remove these biases apart from removing these defects from the datasets (see 'Green Defects (Human Independent above)). This however, can lead to an underestimate of the true impact of rejuvenation on improving coffee quality. To account for this, we have included a Human Biased dataset.

The analysis of this human-biased dataset revealed patterns closely matching the previous findings. As with human-independent defects, insect damage accounted for the majority of defect mass, and defect mass generally decreased with elevation due to diminishing pest pressure. Across all sites, the average reduction in defect mass within the human-biased category was 28.9%, closely paralleling the human-independent dataset (Table 03).

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It is important to note that this figure does not include defects originating from cherries previously removed during initial sorting. This was done to avoid compromising cupping quality evaluations by introducing defects that are difficult or impossible to spot by eye. Had these cherries been reintroduced into the green coffee samples, the overall defect mass would likely have increased, potentially amplifying differences between stumped and unstumped treatments further. Future studies are recommended to specifically investigate how rejuvenation pruning impacts green coffee composition when human-biased defects are fully accounted for.

Nevertheless, the current data strongly support the conclusion that stumped coffee consistently exhibits reduced defect levels compared to unstumped coffee, even when considering human-related biases. Thus, rejuvenation pruning should be actively promoted among coffee producers as an effective approach to improving overall green coffee quality.

Green Analysis (Processing Defects)

Coffee samples from rejuvenated trees had significantly lower incidence of broken beans after hulling. Breakage incurred during hulling was 32.1 % less in stumped coffee as compared to unstumped coffee at the lowland site. At the midland site, breakage was 47.6 % less in stumped coffee samples. No significant change was observed at the highland site, where baseline breakage was already negligible (see Appendix X). In the highlands however, cool temperatures already promote hard-bean formation, so both pruned and unpruned trees yield seeds robust enough to sufficiently withstand the rigors of hulling.

At elevations where hulling was significantly different, there are likely two mechanisms at play to help explain this pattern. Firstly, stumped coffee trees likely produce beans with stronger internal structures. With improved nutrient flows and a better leaf area to fruit ratio, stumped trees allocate more minerals and nutrients to each seed, producing better filled seeds with thicker cell walls and eliminating the internal voids typical of source-limited beans. Better-filled, denser seeds withstand the mechanical stress of the dehuller far more effectively. Secondly, stumping cut insect damage by a significant amount. The absence of borer holes and galleries removes

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weak planes that would otherwise fracture under impact in the huller. With this in consideration, the benefit stumping imparts on reducing broken beans is greatest where beans are naturally softer and more pest exposed, which in this case was at the lowland and midland elevations.

These findings demonstrate that stumping substantially reduces bean breakage in environments where softer beans and higher pest pressures are prevalent, namely, lowland and midland sites. Though the absolute volumes of broken beans may seem small, these defects accumulate at scale, and can significantly impact commercial profitability. Therefore, coffee farmers and producers at low to mid-elevations are strongly encouraged to implement rejuvenation practices to minimize processing related quality losses, improving overall marketable coffee yields and profitability.

Bean Size and Density

Bean size was consistently larger in stumped coffee compared to unstumped coffee across all elevations. Specifically, the proportion of small beans (< screen-14) in stumped coffee was 24.5% lower at the lowland site, 36.4% lower at the midland site, and 27.4% lower at the highland site (see Appendix X). Despite these significant differences in bean size, no differences in bean density between stumped and unstumped samples were observed at any elevation.

This pattern, again, can likely be attributed to the source–sink interpretation from earlier. Rejuvenated coffee trees maintain better leaf-area-to-fruit ratios and improved nutrient flows, which ensure higher allocation of carbohydrates and minerals to developing seeds, resulting in larger, better-filled beans. In contrast, older, unstumped trees likely continue to enlarge the less demanding watery mesocarp but leave the seeds under-filled, producing a higher share of sub-screen-14 beans even though overall cherry mass is greater.

The improved bean size associated with stumped coffee carries important commercial implications. In Ethiopia, coffee below screen-14 is sorted out and not sold for export. Therefore, reducing the mass of under screen coffee can improve outturn of quality exportable coffee, secure higher prices and boost profitability. For coffee

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farmers and producers, adopting and promoting rejuvenation can substantially reduce losses incurred during coffee grading and cleaning processes. The 24 % to 36 % reduction in undersized beans identified in this study translates directly into increased volumes of marketable, higher-quality coffee, emphasizing the economic benefit of adopting rejuvenation practices.

Cupper Bias Analysis

Q-grader comparisons show that sensory results are robust. Across 116 paired evaluations the two Q-graders agreed on most attributes, and when significant differences did appear they were attribute-specific, moderate in magnitude, and evenly distributed with Cupper A rated some dimensions higher (e.g., lowland aroma, midland body) while rating others lower (midland acidity). Critically, there was no systematic bias favoring either stumped or unstumped lots, and total cup score discrepancies never exceeded 0.43 points for any elevation. Moreover, the highland data, where stumped versus unstumped cup scores were most divergent, showed almost perfect Q-grader alignment, reinforcing the credibility of that treatment effect. Finally, uniform 10.0 ratings for Sweetness, Uniformity, and Clean Cup across all samples indicate that both graders operated from the same calibration baseline. Taken together, these patterns confirm that observed quality differences reflect the coffees themselves rather than Q-grader bias.

Cupping Results

Our findings clearly demonstrate that stumping coffee trees directly improves cup quality across all elevations. Stumped coffee consistently scored higher than unstumped coffee, with mean total cup-score increases of 2.37 points at the lowland site, 1.65 points at the midland site, and 3.26 points at the highland site (see Appendix X). These sensory improvements were observed uniformly across all cup attributes including fragrance/aroma, flavor, acidity, body, aftertaste, balance, and overall impression, with moderate to very large effect sizes. Sweetness, uniformity, and clean cup scores remained uniformly high (10.0), indicating that both treatments maintained basic expectations of specialty-grade standards, and observed differences primarily reflect positive cup enhancement rather than defect suppression.

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Two interrelated mechanisms, as mentioned previously, likely explain this observation. First, Rejuvenation pruning promotes healthier nutrient and mineral flows within the tree, resulting in larger, denser beans with improved biochemical composition. Such beans roast more evenly, producing richer and more complex flavor profiles through enhanced Maillard reactions and caramelization. Secondly, stumped samples consistently contained fewer insect damaged beans and fewer undersized beans. This reduction in defects and improved size uniformity contributes directly to more uniform roasting, clearer flavor expression, and fewer muted or off-flavor notes. The Q-graders' qualitative comments that stumped coffees were "more expressive of terroir" while unstumped cups appeared "muted", support this interpretation.

The magnitude of sensory improvement varied by altitude, with highland coffees showing the greatest cup-score gains (>3 points). This pronounced improvement likely reflects the inherently higher flavor potential of highland grown coffee, which is slower maturing, denser, and possibly more sensitive to minor quality enhancements. In our study, even modest reductions in defects or improvements in bean development can significantly amplify their already superior sensory potential. Midland and lowland coffees also improved notably, but their potential for flavor expression remains comparatively limited by environmental constraints.

Rigorous controls limited biases related to post-harvest processing and analyses confirmed the absence of Q-grade bias, reenforcing that the observed sensory improvements can be attributed to the practice of stumping and the biophysical changes within rejuvenated coffee trees. A two to three point cup score increase carries substantial commercial implications, often enabling coffees to move into higher value specialty pricing categories. Consequently, we strongly recommend that coffee farmers, producers, and industry stakeholders promote and adopt rejuvenation practices to reliably enhance coffee quality and profitability, especially in highland regions where the potential for sensory improvement is greatest.

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Conclusion

This study clearly demonstrates substantial economic and quality-related benefits from rejuvenating older coffee trees through stumping. Across all elevations evaluated, stumped coffee consistently outperformed unstumped coffee in key quality attributes, directly translating into increased profitability and improved market positioning for farmers and coffee producers.

This study clearly demonstrates substantial economic and quality related benefits from rejuvenating older coffee trees through stumping. Across all elevations studied, stumped coffee consistently outperformed unstumped coffee across multiple quality attributes, directly translating into increased profitability and improved market positioning for farmers and producers.

To provide practical insight into the economic implications of rejuvenation pruning for coffee operations, we have included an economic assessment below. It is important to acknowledge that estimating exact profit impacts is inherently challenging due to the volatility of coffee prices and the numerous external factors influencing FOB (free-on-board) coffee pricing. Consequently, the following analysis should **not be directly interpreted**. Rather, we recommend that stakeholders apply their specific costs, selling prices, and operational contexts to our cherry delivery, green defect and quality estimates to calculate profit impacts relevant to their own circumstances. The calculations presented here serve as a practical guideline, rather than precise forecasts.

Our economic analysis suggests a notable financial impact related to the observed differences in rejuvenation. Specifically, we estimate an average profit loss of $2,869.06 USD per container (19,200 kg) of green coffee produced from unstumped coffee trees compared to rejuvenated ones (Table 04). This loss primarily stems from increased cherry defects, green bean defects, and under-screen beans. It is important to note that this estimate assumes a full transition from 100% unstumped to 100% rejuvenated coffee trees.

Table 03. Simplified overview of average coffee improvements across all sites as identified in this study that were be attributed to the stumping of coffee trees.

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Quality Attribute	Description	Stumped	Unstumped	Difference	Change ↔	% Difference
Ripe Cherry Deliveries	Cherry deliveries from stumped coffee trees were found to have greater proportions of ripe cherry.	72.8kg	63.1kg	9.7kg	Unst. ↓ St.	15.3%
Cherry Mass	Cherry mass was found to be larger in unstumped coffee cherry.	83.7g	86.3g	2.6g	Unst. ↑ St.	3.0%
Green Defects (Human Independent)	Green coffee defects inherent to coffee trees (occurring independently of human interference) were lower in stumped coffee samples.	9.6g	13.7g	4.1g	Unst. ↓ St.	-29.9%
Green Defects (Human Bias)	Green coffee defects potentially influenced by human bias were lower in stumped coffee samples.	10.1g	14.2g	4.1g	Unst. ↓ St.	-28.9%
Green Defects (Processing)	Green coffee defects caused by the action of hulling the coffee were lower in stumped coffee samples.	2.2g	3.4g	1.2g	Unst. ↓ St.	-35.3%
Bean Size (Screen-14)	Coffee sample mass falling through Screen-14 were found to be lower in stumped coffee samples.	15.3g	21.6g	6.3g	Unst. ↓ St.	-29.2%
Cup Score	Coffee cup scores were found to be higher in stumped coffee samples.	84	81.5	2.5	Unst. ↓ St.	3.1%

The potential profit gains from stumping are even more pronounced when considering sensory quality improvements. On average, stumping improved coffee cup scores by 2.5 points across all sites. Utilizing data from the 2024 Specialty Coffee Transaction Guide (2025), this sensory improvement equates to an estimated additional profit of $21,164.16 USD per container of exported coffee (Table 05). When combined with the reduced losses from improved cherry and green bean quality, rejuvenation pruning could increase total profits by approximately $24,033.22 USD per container of green coffee produced and sold for export.

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Table 04. Estimated profit loss of coffee operations in the preparation of one container (19,200kgs) of export coffee that area associated with differences in stumped and unstumped coffee cherry deliveries and green bean defects as per the combined average differences across all experimental sites.

Quality Attribute	Avg. Observed Quantity Diff.	Diff. Equivalent (1 Container, 19,200kgs)	% Maintained after Cleaning#	Final Mass Lost	Profit Lost (USD)^
Defect Cherry Deliveries*	9.7kg per 100Kg	465.6+	5%	456.6kg	$1,272.81
Green Defects	4.1g per 350g	224.9kg	5%	213.7kg	$584.07
Green Defects (Processing)	1.2g per 350g	65.8kg	10%	59.2kg	$161.89
Under Screen-14	6.3g per 350g	345.6kg	10%	311.0kg	$850.29
TOTAL	-	**1,101.9kg**	-	**1,049.5kg**	**$2,869.06**

Note: #Percentage displayed represents the estimated amount of the respective defect type that would likely remain in the final exportable coffee; ^Calculated assuming a selling price of $3.54/lb. which was derived from the 2024 Specialty Coffee Transaction Guide and represents the 3-year average median fob selling price for 84 to 85.9 point coffees, additionally prices were reduced by the Export Floor Price of 'Under Grade Yirgacheffe' coffee as set by the Ethiopian Coffee and Tea Authority on 8-04-2025 at $2.30/lb.; *Values were calculated assuming 115,200kg of cherry are needed to produce one container of coffee representing a 1:6 outturn ratio of cherry to green coffee; +value displayed was calculated assuming 50% of the reject cherry would result in severe green defects meaning that the total mass of green coffee from reject coffee would be 2 times what is displayed.

In conclusion, rejuvenation, or stumping, is a demonstrably effective practice for enhancing coffee quality and substantially improving the economic outcomes for coffee operations. Farmers and producers who adopt systematic rejuvenation practices stand to benefit from increased marketable coffee volumes, improved quality scores, and higher profitability, and ultimately enhancing their competitive advantage within the global coffee market.

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Table 05. Estimated profit addition of coffee operations in the export sale of one container of coffee that can be attribute to sensory quality difference between stumped and unstumped coffee.

	Avg. Cup Point Increase	Value (USD)/Cup Point#	Value (USD)Addition /lb.^	Total Potential Value Addition (1 container, 19,200Kg)
Cup Score	2.5 pts	$0.20	$0.50	$21,164.16

Note: #Calculated from data in the 2024 Specialty Coffee Transaction Guide and represents the average per cup point change in the 3-year median fob coffee sales price difference for coffees with cupping scores between 80 and 85.9 points; ^Calculated by multiplying 'Avg. Cup Point Increase' by 'Value ($)/Cup Point' to calculate the total observed value addition that can be attributed to the average rise in observed cup scores.

Future Areas of Study

Below is a list of recommended studies to further explore and better understand the impacts of rejuvenation or stumping on coffee quality.

- Long-term Yield and Quality Trajectories

The current study only captures one harvest cycle at two-years post stumping. Further studies are needed to determine how the observed patterns will change with time. In doing so, producers would be better equipped to make informed management decisions on the farm and with rotation stumping regimes.

- Cherry Mass v Bean Size

Although difference in cherry mass and bean size were observed, further studies would be needed to determine the exact impacts stumping on cherry mass outturn to green coffee mass.

- Cherry-ripening dynamics and harvest behavior

It was not clear if the observed improvements in coffee quality were biased by humans. Future studies could look into the ripening dynamics of stumped coffee trees and the physical structure of the tree canopy on harvester ability and efficiency in harvesting ripe coffee cherry.

- Full accounting of human-biased green defects

Future studies are recommended to specifically investigate how stumping impacts green coffee composition when human-biased defects are fully accounted for.

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- Post-harvest Process Interactions

Further studies are required to determine if the benefits imparted by stumping on coffee quality also apply to other coffee processing techniques (i.e. washed honey, carbonic maceration, anerobic fermentation, etc.).

- Cultivar Specific Responses

This study combined all coffee varietals into single deliveries. Further research is needed to determine if the benefits imparted by stumping on coffee quality affect all coffee varietals found in the Gedeo Zone equally.

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Appendix I T-test results comparing the cherry delivery compositions from stumped and unstumped coffee trees at all experimental sites in Gedeo Zone, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
	St.	Unst.	St.	Unst.	St.	Unst.				Lower	Upper	
Lowland Site												
Mean % Floater Cherry	9	8	6.66	7.49	1.39	1.82	13	-1.04	0.31	-0.88	2.54	0.52
Mean % Sorted Reject Cherry	8	9	19.77	26.62	6.06	9.86	13	-1.75	0.10	-1.62	15.33	0.82
Mean % Total Reject Cherry	8	9	26.40	34.88	5.28	8.41	14	-2.52	0.02	1.25	15.70	1.19
Mean % Ripe Cherry	8	9	73.59	65.12	5.28	8.41	14	2.52	0.02	-15.70	-1.25	-1.19
Midland Site												
Mean % Floater Cherry		10	9.07	9.13	1.76	1.14	9	-0.09	0.92	-1.44	1.33	-0.03
Mean % Sorted Reject Cherry		10	23.89	33.65	7.72	6.60	9	-2.60	0.03	-18.26	-1.27	-0.82
Mean % Total Reject Cherry		10	32.96	42.78	8.25	6.23	9	-2.79	0.02	-17.79	-1.85	-0.88
Mean % Ripe Cherry		10	67.03	57.21	8.25	6.23	9	2.79	0.02	1.85	17.79	0.88
Highland Site												
Mean % Floater Cherry	9	11	5.80	5.71	1.67	1.58	17	0.12	0.90	-1.63	1.46	-0.05
Mean % Sorted Reject Cherry	9	11	16.51	27.24	8.89	11.12	18	-2.40	0.02	1.34	20.14	1.05
Mean % Total Reject Cherry	9	11	22.31	32.96	9.90	10.95	18	-2.28	0.03	0.84	20.46	1.01
Mean % Ripe Cherry	9	11	77.69	67.04	9.90	10.95	18	2.28	0.03	-20.46	-0.84	-1.01

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Appendix II T-test results comparing the brix (% sugar), cherry mass, density and bean size between stumped and unstumped coffee cherry deliveries at all experimental sites in Gedeo Zone, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
			St.	*Unst.*	*St.*	*Unst.*				Lower	Upper	
Lowland Site												
	St.	Unst.										
Brix (% Sugar)	81		12.87	13.07	2.02	1.92	92	-0.99	0.32	-0.59	0.20	-0.10
Cherry Mass (g)	81		81.77	83.12	5.18	5.98	80	-2.51	0.01	-2.42	-0.28	-0.27
Density (g/lt)	17	18	753.67	758.53	30.79	51.83	28	-0.34	0.73	-24.47	34.18	0.11
Bean Size - Screen-14 (g)	18		19.11	25.27	6.48	8.48	17	-2.98	< 0.001	-10.52	-1.80	-0.70
Midland Site												
	St.	Unst.										
Brix (% Sugar)	99	100	14.17	14.26	1.38	1.87	193	-0.49	0.62	-0.29	0.44	0.07
Cherry Mass (g)	88	95	88.43	88.55	3.15	2.35	181	-0.42	0.66	-0.21	0.34	0.06
Density (g/lt)	20		770.58	763.80	38.00	50.30	19	1.64	0.12	-1.88	15.45	0.37
Bean Size – Screen-14 (g)	20		12.62	19.82	2.27	4.02	19	-6.43	0.00	-9.55	-4.86	-1.44
Highland Site												
	St.	Unst.										
Brix (% Sugar)	90	110	14.04	14.50	1.66	1.30	166	-2.11	0.03	0.03	0.88	0.31
Cherry Mass (g)	90	101	81.04	87.41	5.45	4.99	183	-8.52	< 0.001	4.89	7.83	1.22
Density (g/lt)	18	22	778.39	774.32	39.87	56.73	37	0.26	0.79	-35.04	27.01	-0.08
Bean Size – Screen-14 (g)	18	22	14.34	19.71	2.82	3.54	38	-5.33	< 0.001	3.33	7.41	1.65

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<u>Appendix III</u> T-test results comparing the mass (g) of green bean defects per 350g samples from stumped and unstumped coffee trees (excluding potential human bias) across all experimental sites in Gedeo Zone, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P	CI (95%)		Effect
	St.	Unst.	*St.*	*Unst.*	*St.*	*Unst.*			(0.05)	Lower	Upper	Size
Lowland Site												
Severe Insect Damage (g)	18	14	1.24	2.13	0.68	0.48	30	-4.29	< 0.001	0.46	1.31	1.46
Slight Insect Damage (g)	17	18	11.75	19.88	4.65	7.53	29	-3.86	< 0.001	3.82	12.43	1.29
Withered (g)	18		0.08	0.09	0.13	0.11	17	-0.34	0.73	-0.10	0.07	-0.08
Shell (g)	18		2.51	3.60	1.17	3.26	17	-1.59	0.13	-2.52	0.35	-0.37
Total Primary Defects (g)	18	14	1.24	2.13	0.68	0.48	30	-4.29	< 0.001	0.46	1.31	1.46
Total Secondary Defects (g)	17	18	14.42	23.58	5.20	9.09	27	-3.68	< 0.001	4.05	14.26	1.23
Total Defects (g)	17	18	16.52	25.88	8.26	10.02	32	-3.02	< 0.001	3.04	15.66	1.01
Midland Site												
Severe Insect Damage (g)	20		0.64	1.02	0.43	0.56	19	-2.4	0.02	-0.72	-0.05	-0.54
Slight Insect Damage (g)	20		6.35	7.68	4.08	3.98	19	-1.33	0.20	-3.42	0.76	-0.30
Withered (g)	20		0.01	0.07	0.03	0.08	19	-3.68	< 0.001	-0.10	-0.03	-0.82
Shell (g)	20		1.83	1.56	1.11	0.72	19	1.11	0.28	-0.24	0.78	0.25
Total Primary Defects (g)	20		0.64	1.02	0.43	0.56	19	-1.45	0.16	-2.70	0.49	-0.32
Total Secondary Defects (g)	20		8.19	9.32	4.79	4.18	19	-0.97	0.34	-3.55	1.30	-0.22
Total Defects (g)	20		8.83	10.34	5.01	4.56	19	-1.23	0.23	-4.08	1.06	-0.28
Highland Site												
Severe Insect Damage (g)	18	22	0.07	0.42	0.09	0.40	24	-3.92	< 0.001	-1.93	10.31	0.46
Slight Insect Damage (g)	18	22	1.71	3.63	0.85	2.12	29	-3.87	< 0.001	-1.96	11.82	0.48
Withered (g)	18	22	0.01	0.01	0.03	0.06	34	-0.33	0.74	-2.00	13.31	0.49
Shell (g)	18	22	0.89	0.83	0.81	0.54	29	0.26	0.79	-1.29	12.03	0.54
Total Primary Defects (g)	18	22	0.07	0.42	0.09	0.40	24	-3.92	< 0.001	-1.93	10.31	0.46
Total Secondary Defects (g)	18	22	2.61	4.47	1.44	2.31	36	-3.11	< 0.001	-2.13	13.99	0.49
Total Defects (g)	18	22	3.59	4.97	1.91	2.61	38	-1.94	0.06	-1.81	14.83	0.52

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Appendix IV T-test results comparing the mass (g) of green bean defects per 350g samples from stumped and unstumped coffee trees (including potential human bias) at the lowland site in Dilla, Gedeo, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
			St.	*Unst.*	*St.*	*Unst.*				Lower	Upper	
Lowland Site	St.	Unst.										
Full Black (g)		18	0.005	0.005	0.02	0.02	17	-0.05	1.00	-0.01	0.01	0.00
Full Sour (g)		18	0.02	0.24	0.04	0.64	17	-1.45	0.16	-0.55	0.10	-0.34
Fungus Damage (g)		18	0.02	0.06	0.08	0.12	17	-1.07	0.29	-0.11	0.04	-0.25
Severe Insect Damage (g)	18	14	1.24	2.13	0.68	0.48	30	-4.29	< 0.001	0.46	1.31	1.46
Primary Defects (g)		17	1.19	2.43	0.62	1.16	17	-4.45	0.00	-1.82	-0.64	-1.08
Partial Black (g)		18	0.01	0.05	0.04	0.08	17	-1.76	0.10	-0.07	0.01	-0.41
Partial Sour (g)	18	16	0.11	0.20	0.12	0.12	31	-2.10	0.04	0.002	0.17	0.72
Immature (g)		18	0.01	0.02	0.02	0.04	17	-1.00	0.33	-0.04	0.01	-0.23
Withered (g)		18	0.08	0.09	0.13	0.12	17	-0.34	0.73	-0.10	0.07	-0.08
Shell (g)		18	2.51	3.60	1.17	3.26	17	-1.59	0.13	-2.52	0.35	-0.37
Slight Insect Damage (g)	17	18	11.75	19.88	4.65	7.53	29	-3.86	< 0.001	3.82	12.43	1.29
Secondary Defects (g)	17	18	14.55	24.16	5.21	9.20	27	-3.82	< 0.001	4.46	14.76	1.27
Total Defects (g)		18	17.46	26.77	8.67	10.23	17	-3.10	0.006	2.98	15.65	0.73

Research was funded by the USDA funded Regrow Yirga Project implemented by TechnoServe.

Appendix V T-test results comparing the mass (g) of green bean defects per 350g samples from stumped and unstumped coffee trees (including potential human bias) at the midland site in Wonago, Gedeo, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
Midland Site	**St.**	**Unst.**	***St.***	***Unst.***	***St.***	***Unst.***				**Lower**	**Upper**	
Full Black (g)	20		0.004	0.004	0.02	0.02	19	0.00	1.00	-0.01	0.01	0.00
Full Sour (g)	20		0.02	0.01	0.04	0.04	19	0.57	0.58	-0.02	0.03	0.13
Fungus Damage (g)	20		0.02	0.06	0.004	0.10	19	-1.42	0.17	-0.10	0.02	-0.31
Severe Insect Damage (g)	13	10	0.78	1.13	0.07	0.05	21	-3.41	< 0.001	0.14	0.57	1.39
Primary Defects (g)	20		0.78	1.26	0.26	0.22	10	-4.15	< 0.001	-0.74	-0.22	-1.25
Partial Black (g)	20		0.03	0.02	0.06	0.05	19	0.29	0.77	-0.04	0.05	0.06
Partial Sour (g)	20		0.17	0.25	0.15	0.18	19	-1.75	0.10	-0.19	0.02	-0.39
Immature (g)	20		0.09	0.12	0.14	0.20	19	-0.67	0.51	-0.12	0.06	-0.15
Withered (g)	20		0.001	0.07	0.03	0.08	19	-3.68	< 0.001	-0.10	-0.03	-0.82
Shell (g)	20		1.83	1.56	1.11	0.72	19	1.11	0.28	-0.24	0.78	0.25
Slight Insect Damage (g)	20		6.35	7.68	4.08	3.98	19	-1.33	0.20	-3.42	0.76	-0.30
Secondary Defects (g)	20		8.48	9.72	4.93	4.24	19	-1.05	0.30	-3.68	1.22	-0.23
Total Defects (g)	20	19	9.17	10.68	5.16	4.68	37	-0.96	0.34	0.52	18.7	0.71

Research was funded by the USDA funded Regrow Yirga Project implemented by TechnoServe.

Appendix VI T-test results comparing the mass (g) of green bean defects per 350g samples from stumped and unstumped coffee trees (including potential human bias) at the highland site in Dumerso, Gedeo, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
			St.	Unst.	St.	Unst.				Lower	Upper	
Highland Site	St.	Unst.										
Full Black (g)	18	22	0.00	0.02	0.00	0.05	21	-2.32	0.03	-1.49	9.60	0.49
Full Sour (g)	18	22	0.02	0.02	0.05	0.06	38	0.22	0.82	-2.26	14.50	0.49
Fungus Damage (g)	18	22	0.00	0.03	0.00	0.07	21	-2.16	0.04	-1.47	9.61	0.49
Severe Insect Damage (g)	18	22	0.07	0.42	0.09	0.40	24	-3.92	< 0.001	-1.93	10.31	0.46
Primary Defects (g)	18	22	0.09	0.49	0.09	0.43	23	-4.23	< 0.001	-1.91	10.04	0.46
Partial Black (g)	18	22	0.00	0.01	0.00	0.04	21	-1.45	0.16	-1.33	9.65	0.51
Partial Sour (g)	18	22	0.13	0.14	0.09	0.11	38	-0.37	0.71	-2.35	14.46	0.48
Immature (g)	18	22	0.02	0.06	0.07	0.14	32	-1.20	0.23	-2.06	12.64	0.48
Withered (g)	18	22	0.01	0.01	0.03	0.06	34	-0.33	0.74	-2.00	13.31	0.50
Shell (g)	18	22	0.89	0.84	0.81	0.54	29	0.26	0.80	-1.29	12.04	0.54
Slight Insect Damage (g)	18	22	1.71	3.63	0.85	2.21	29	-3.87	< 0.001	-1.96	11.82	0.48
Secondary Defects (g)	18	22	2.77	4.69	1.49	2.29	36	-3.21	< 0.001	-2.11	14.01	0.50
Total Defects (g)	18	22	3.60	5.19	1.89	2.60	38	-2.23	0.03	-1.87	14.81	0.52

Research was funded by the USDA funded Regrow Yirga Project implemented by TechnoServe.

Appendix VII T-test results comparing the cupping results of participating Q-graders to identify potential sources of inherent bias in their scores within stumped coffee samples.

	# Obs.	Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
		Cupper A	Cupper B	Cupper A	Cupper B				Lower	Upper	
Lowland Site											
Frag./Aroma	18	7.71	7.54	0.23	0.21	17	3.12	0.01	0.05	0.28	0.73
Acidity	18	7.74	7.79	0.22	0.25	17	-0.81	0.43	-0.20	0.09	-0.19
Flavor	18	7.64	7.53	0.18	0.21	17	2.41	0.03	0.01	0.21	0.57
Body	18	7.69	7.65	0.16	0.23	17	0.90	0.38	-0.06	0.14	0.21
Aftertaste	18	7.64	7.64	0.20	0.21	17	0.00	1.00	-0.10	0.10	0.00
Balance	18	7.68	7.58	0.24	0.30	17	1.94	0.07	-0.01	0.20	0.46
Sweetness	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Uniformity	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Clean Cup	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Overall	18	7.67	7.60	0.19	0.26	17	1.76	0.10	-0.01	0.15	0.42
Cup Score	18	83.76	83.33	1.21	1.10	17	3.02	0.01	0.13	0.73	0.71
Midland Site											
Frag./Aroma	20	7.63	7.63	0.25	0.22	19	0.00	1.00	-0.13	0.13	0.00
Acidity	20	7.63	7.76	0.26	0.25	19	-2.34	0.03	-0.26	-0.01	-0.52
Flavor	20	7.60	7.56	0.21	0.23	19	0.90	0.38	-0.05	0.12	0.20
Body	20	7.73	7.58	0.16	0.23	19	3.94	< 0.001	0.07	0.23	0.88
Aftertaste	20	7.60	7.43	0.21	0.26	19	3.62	0.002	0.07	0.28	0.81
Balance	20	7.59	7.60	0.20	0.19	19	-0.37	0.72	-0.08	0.06	-0.08
Sweetness	20	10.00	10.00	0.00	0.00	19	NA	1.00	NA	NA	NA
Uniformity	20	10.00	10.00	0.00	0.00	19	NA	1.00	NA	NA	NA
Clean Cup	20	10.00	10.00	0.00	0.00	19	NA	1.00	NA	NA	NA
Overall	20	7.63	7.64	0.17	0.27	19	-0.25	0.80	-0.12	0.09	-0.06
Cup Score	20	83.39	83.19	1.27	1.17	19	1.45	0.16	-0.09	0.49	0.32
Highland Site											
Frag./Aroma	18	7.81	7.82	0.16	0.27	17	-0.21	0.83	-0.15	0.12	-0.05
Acidity	18	7.96	7.86	0.13	0.23	17	1.59	0.13	-0.03	0.23	0.38
Flavor	18	7.83	7.83	0.17	0.23	17	0.00	1.00	-0.10	0.10	0.00
Body	18	7.89	7.85	0.13	0.21	17	0.82	0.42	-0.06	0.15	0.19
Aftertaste	18	7.79	7.78	0.21	0.24	17	0.21	0.83	-0.12	0.15	0.05
Balance	18	7.93	7.93	0.12	0.17	17	0.00	1.00	-0.07	0.07	0.00
Sweetness	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Uniformity	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Clean Cup	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Overall	18	7.96	7.94	0.10	0.16	17	0.37	0.72	-0.07	0.09	0.09
Cup Score	18	85.17	85.01	0.70	0.74	17	1.13	0.28	-0.13	0.44	0.27

Research was funded by the USDA funded Regrow Yirga Project implemented by TechnoServe.

Appendix VIII T-test results comparing the cupping results of participating Q-graders to identify potential sources of inherent bias in their scores within unstumped coffee samples.

	# Obs.	Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
		Cupper A	Cupper B	Cupper A	Cupper B				Lower	Upper	
Lowland Site											
Frag./Aroma	18	7.22	7.28	0.32	0.31	17	-0.72	0.48	-0.22	0.11	-0.17
Acidity	18	7.32	7.40	0.24	0.35	17	-1.00	0.33	-0.26	0.09	-0.23
Flavor	18	7.25	7.21	0.26	0.25	17	0.72	0.48	-0.08	0.16	0.17
Body	18	7.46	7.43	0.18	0.17	17	0.52	0.61	-0.08	0.14	0.12
Aftertaste	18	7.25	7.24	0.27	0.28	17	0.19	0.85	-0.14	0.17	0.04
Balance	18	7.32	7.36	0.22	0.23	17	-0.53	0.60	-0.21	0.12	-0.12
Sweetness	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Uniformity	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Clean Cup	18	10.00	10.00	0.00	0.00	17	NA	1.00	NA	NA	NA
Overall	18	7.36	7.26	0.23	0.23	17	1.51	0.15	-0.04	0.23	0.36
Cup Score	18	81.18	81.18	1.42	1.22	17	0.00	1.00	-0.51	0.51	0.00
Midland Site											
Frag./Aroma	20	7.40	7.33	0.34	0.29	19	1.10	0.28	-0.07	0.22	0.25
Acidity	20	7.43	7.50	0.24	0.37	19	-1.19	0.25	-0.21	0.06	-0.27
Flavor	20	7.33	7.20	0.23	0.35	19	2.36	0.03	0.01	0.24	0.53
Body	20	7.53	7.51	0.24	0.29	19	0.21	0.83	-0.11	0.14	0.05
Aftertaste	20	7.23	7.28	0.24	0.30	19	-0.85	0.41	-0.17	0.07	-0.19
Balance	20	7.33	7.43	0.27	0.26	19	-2.03	0.06	-0.20	0.00	-0.45
Sweetness	20	10.00	10.00	0.00	0.00	19	NA	1.00	NA	NA	NA
Uniformity	20	10.00	10.00	0.00	0.00	19	NA	1.00	NA	NA	NA
Clean Cup	20	10.00	10.00	0.00	0.00	19	NA	1.00	NA	NA	NA
Overall	20	7.44	7.39	0.24	0.25	19	0.94	0.36	-0.06	0.16	0.21
Cup Score	20	81.66	81.63	1.64	1.54	19	0.27	0.79	-0.25	0.33	0.06
Highland Site											
Frag./Aroma	22	7.41	7.43	0.26	0.44	21	-0.36	0.72	-0.15	0.11	-0.08
Acidity	22	7.51	7.55	0.22	0.34	21	-0.51	0.61	-0.17	0.10	-0.11
Flavor	22	7.35	7.34	0.21	0.38	21	0.2	0.85	-0.11	0.13	0.04
Body	22	7.51	7.36	0.12	0.32	21	2.14	0.04	0.00	0.29	0.46
Aftertaste	22	7.30	7.28	0.23	0.35	21	0.21	0.83	-0.10	0.12	0.05
Balance	22	7.36	7.41	0.24	0.26	21	-1.00	0.33	-0.14	0.05	-0.21
Sweetness	22	10.00	10.00	0.00	0.00	21	NA	1	NA	NA	NA
Uniformity	22	10.00	10.00	0.00	0.00	21	NA	1	NA	NA	NA
Clean Cup	22	10.00	10.00	0.00	0.00	21	NA	1	NA	NA	NA
Overall	22	7.41	7.43	0.23	0.27	21	-0.49	0.63	-0.12	0.07	-0.10
Cup Score	22	81.85	81.81	1.3	1.85	21	0.25	0.81	-0.34	0.43	0.05

Research was funded by the USDA funded Regrow Yirga Project implemented by TechnoServe.

Appendix IX T-test results comparing the cupping results of stumped and unstumped coffee samples across all experimental sites in Gedeo Zone, Ethiopia.

	# Obs.		Mean		St. Dev.		df	t-stat.	P (0.05)	CI (95%)		Effect Size
			St.	Unst.	St.	Unst.				Lower	Upper	
Lowland Site												
Frag./Aroma	36		7.62	7.25	0.20	0.31	35	6.50	0.00	0.26	0.49	1.08
Acidity	36		7.76	7.36	0.23	0.30	35	7.12	0.00	0.29	0.52	1.19
Flavor	36		7.58	7.23	0.20	0.25	35	8.08	0.00	0.26	0.44	1.35
Body	36		7.67	7.44	0.19	0.17	35	5.86	0.00	0.15	0.31	0.98
Aftertaste	36		7.63	7.24	0.20	0.27	35	9.02	0.00	0.31	0.48	1.50
Balance	36		7.63	7.34	0.27	0.22	35	5.06	0.00	0.17	0.41	0.84
Sweetness	36		10.00	10.00	0.00	0.00	35	NA	1.00	NA	NA	NA
Uniformity	36		10.00	10.00	0.00	0.00	35	NA	1.00	NA	NA	NA
Clean Cup	36		10.00	10.00	0.00	0.00	35	NA	1.00	NA	NA	NA
Overall	36		7.63	7.31	0.23	0.23	35	6.74	0.00	0.22	0.42	1.12
Cup Score	36		83.55	81.18	1.16	1.30	35	9.78	0.00	1.88	2.86	1.63
Midland Site												
Frag./Aroma	40		7.62	7.36	0.23	0.31	39	4.37	0.00	0.14	0.38	0.69
Acidity	40		7.69	7.46	0.26	0.31	39	4.01	0.00	0.11	0.35	0.63
Flavor	40		7.58	7.26	0.21	0.30	39	6.30	0.00	0.22	0.42	0.99
Body	40		7.65	7.52	0.21	0.26	39	2.99	0.00	0.04	0.22	0.47
Aftertaste	40		7.51	7.25	0.25	0.27	39	5.27	0.00	0.16	0.36	0.83
Balance	40		7.59	7.37	0.19	0.26	39	5.07	0.00	0.13	0.31	0.80
Sweetness	40		10.00	10.00	0.00	0.00	39	NA	1.00	NA	NA	NA
Uniformity	40		10.00	10.00	0.00	0.00	39	NA	1.00	NA	NA	NA
Clean Cup	40		10.00	10.00	0.00	0.00	39	NA	1.00	NA	NA	NA
Overall	40		7.63	7.41	0.22	0.24	39	4.69	0.00	0.12	0.31	0.74
Cup Score	40		83.29	81.64	1.21	1.57	39	6.06	0.00	1.09	2.19	0.96
Highland Site												
	St.	Unst.										
Frag./Aroma	36	44	7.81	7.42	0.21	0.36	72	5.99	0.00	-0.52	-0.26	-1.28
Acidity	36	44	7.91	7.53	0.19	0.28	75	7.11	0.00	-0.48	-0.27	-1.53
Flavor	36	44	7.83	7.34	0.2	0.31	74	8.58	0.00	-0.60	-0.37	-1.85
Body	36	44	7.87	7.44	0.17	0.25	76	8.97	0.00	-0.53	-0.33	-1.94
Aftertaste	36	44	7.78	7.29	0.22	0.29	78	8.59	0.00	-0.61	-0.38	-1.88
Balance	36	44	7.93	7.39	0.14	0.25	70	12.24	0.00	-0.63	-0.45	-2.61
Sweetness	36	44	10.00	10.00	0.00	0.00	NA	NA	1.00	NA	NA	NA
Uniformity	36	44	10.00	10.00	0.00	0.00	NA	NA	1.00	NA	NA	NA
Clean Cup	36	44	10.00	10.00	0.00	0.00	NA	NA	1.00	NA	NA	NA
Overall	36	44	7.95	7.42	0.13	0.24	68	12.34	0.00	-0.61	-0.44	-2.62
Cup Score	36	44	85.09	81.83	0.71	1.58	62	12.24	0.00	-3.79	-2.73	-2.57

Research was funded by the USDA funded Regrow Yirga Project implemented by TechnoServe.

Appendix X Simplified summary of stumping impacts on various quality attributes of coffee discovered during this study across all sites in the Gedeo Zone, Ethiopia.

Quality Attribute	Lowland Site					Midland Site					Highland Site				
	St.	**Unst.**	**Diff.**	**Change ↔**	**% Diff.**	**St.**	**Unst.**	**Diff.**	**Change ↔**	**% Diff.**	**St.**	**Unst.**	**Diff.**	**Change ↔**	**% Diff.**
Ripe Cherry Deliveries	73.6kg	65.1kg	8.5kg	Unst. ↓ St.	13.0%	67.0kg	57.2kg	9.8kg	Unst. ↓ St.	14.6%	77.7kg	67.0kg	10.7kg	Unst. ↓ St.	13.8%
Cherry Mass	81.8g	83.1g	1.3g	Unst. ↑ St.	1.6%	88.4g	88.5g	0.1g	Unst. ↑ St.	0.1%	81.0g	87.4g	6.4g	Unst. ↑ St.	7.9%
Green Defects (Human Independent)	16.5g	25.9g	9.4g	Unst. ↓ St.	-36.2%	8.8g	10.3	1.5g	Unst. ↓ St.	-14.6%	3.6	5.0	1.4	Unst. ↓ St.	-28.0%
Green Defects (Human Bias)	17.5g	26.8g	9.3g	Unst. ↓ St.	-34.7%	9.2g	10.7g	1.5g	Unst. ↓ St.	-14.0%	3.6g	5.2g	1.6g	Unst. ↓ St.	-30.8%
Green Defects (Processing)	3.6g	5.3g	1.7g	Unst. ↓ St.	-32.1%	2.2g	4.2g	-2.0g	Unst. ↓ St.	-47.6%	0.8g	0.7g	0.1g	Unst. ↓ St.	14.3%
Bean Size (Screen-14)	19.1g	25.3	6.2g	Unst. ↓ St.	-24.5%	12.6g	19.8g	7.2g	Unst. ↓ St.	-36.4%	14.3g	19.7g	5.4g	Unst. ↓ St.	-27.4%
Cup Score	83.5	81.2	2.3	Unst. ↓ St.	2.8%	83.3	81.6	1.7	Unst. ↓ St.	2.1%	85.1	81.8	3.3	Unst. ↓ St.	4.0%

Note: 'Change ↔' refers to the direction in which the '% Diff.' relationship exists. For example, 'Unst. → St.' would infer that the '% Diff.' displayed is the percent change from Unstumped to Stumped and 'St. ← Unst.' Would infer the opposite.

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