Evaluation of Small-Scale Coffee Roasters for Smallholder Kenyan Coffee Farmers

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1. Executive Summary:

Many smallholder coffee farmers in Kenya lack the capital, access and education to technologies that would help them better understand and improve the quality of their coffee beans. By providing a low cost, easy to use, reliable roaster they will be able to taste their product and understand the differences in quality produced by sorting methods and low cost agricultural techniques.Working with Kyle Freedman and Tonny Gitonga, we evaluate existing roasters and research methods of improving bean quality in order to provide a resource for smallholder Kenyan coffee farmers to improve their product and profit.

Though many roasters exist, one that meets the needs of the smallholder coffee farmers in Kenya while being within the farmer's price range ($40-$70) is not available. We evaluate several existing roasters and ways in which tasting coffee can help one understand what measures to take to improve the quality of green coffee beans. After researching and speaking with coffee professionals in the UC Davis coffee lab, we concluded that a roaster would be most beneficial in helping farmers understand how low cost methods of quality control, such as sorting, would affect the taste of coffee and understand why their green coffee beans sell for different prices. By understanding measures to increase the selling price of their coffee beans, they can increase profit. For these reasons, we suggest pairing a roaster with educational workshops aimed at improving quality control methods on the farms.

The evaluation considers important components when introducing a roaster to farmers, who many of, have never roasted coffee beans before. We evaluated cost, being the most important factor, weight (portability), simplicity, consistency (how evenly the beans roast) and safety. Using a SWOT analysis and roasting coffee beans ourselves, we analyzed three coffee roasting devices: the West Bend brand air popcorn popper (traditionally for popcorn, but has been used for at home coffee roasting), the Barwell brand rotating coffee bean roaster, and the Probat small-scale coffee bean roaster. Our evaluation purpose was to determine if there is a product already available that could be used, or moving forward, if we would modify one to meet the needs of the farmers. We concluded that the popcorn popper is the best option, due to its low cost and effectiveness, though modifications to improve safety features and durability will need to be worked on moving forward.

2. Introduction:

Project Statement

Smallholder coffee farmers in the Embu region of Kenya are not earning enough profits from their farms to support their livelihood. Low production quality is the main factor that makes smallholder coffee farms unprofitable. Understanding the way different processing quality control measures can affect the taste of coffee is not commonly known by smallholder farmers because roasters are not easily available and therefore, green beans are sold without being tasted. Working with our clients, Kyle Freedman and Tonny Gitonga, we provide this feasibility study to confirm that providing an affordable roaster in addition to educational workshops to help farmers understand their product will be beneficial in improving the overall quality and profit of coffee beans. This project will begin at the Kamavindi farm in Kenya.

Background

Section 1: Coffee Farming Trends in Kenya

Coffee is ranked #4 in export earnings in Kenya just after tourism, tea and horticulture. Despite its high export quantities, it does not provide enough profits for smallholder coffee farmers to support their livelihood (Karanja). Despite Arabica coffee's high ratings, smallholder coffee farmers are not profiting enough, and production has decreased by 50% over the past 25 years. Many initiatives have been enacted to encourage the sustainable production of coffee, such as the expansion of sustainability certification by NGOs, but coffee farming is not commonly viewed as a stable way of earning income and younger generations are beginning to abandon family farms to pursue other jobs.

The quality of the beans has negatively affected smallholder coffee farmers' profits, but when considering ways to improve the quality of the product, one must consider the cost of improvements. Some of the problems associated with less than premium bean quality, such as pruning, quality control methods, and a lack of training of managing farms can be remedied with training sessions because they are not cost intensive but instead require a change in practice. Due to the high cost of fertilizers and pesticides, improving the beans by these methods may not be feasible and other methods of improvement should be considered such as quality control during different sorting stages. Working with the farmers of the Kamavindi farm and analyzing their current quality control methods and farm practices are the next steps to determine what type of educational workshops would be beneficial.

Though there has been a trend in young farmers leaving the coffee farming business to pursue more stable jobs, those who have continued coffee farming while diversifying their income and taking on entrepreneurial strategies have improved production (Wairegi, et al.). Additionally, younger farmers statistically have smaller farms with higher yields compared to older generation farmers. Smaller farms with higher yields are ideal because less land is needed which results in lower farming costs (Wairegi, et al.). This leaves hope for smallholder coffee production as a viable source of income for smallholder coffee farmers, but yields must be of high quality and sustainable, affordable, improved production methods must be considered.

Section 2: Roaster Considerations

A. Energy Source

When considering the power source of the proposed roaster, we must consider the availability of different types of energy sources. Kenya has a moderately-sized energy sector that is actively growing and set to increase ten-fold in electricity generated in the next decade. Running a coffee roaster requires energy to heat the beans, so access to electricity is critical for farmers to monitor their product. Kenya has several main sources it taps for energy production: oil (imported), geothermal, and hydropower. Thanks to the building of a geothermal plant in the early 2000s, geothermal energy is now the leading method of electricity production in Kenya. Kenya's government is supportive of this energy source and wants to see more, as part of their plan to grow Kenya's transport infrastructure (roads, airports, seaports) and manufacturing capacity.

Despite the rapid growth of Kenya's energy sector, blackouts are still common and many households cannot afford electricity. The expected outcome of the EAPP is that electricity can be distributed faster and cheaper, with fewer gaps in service. In 2017, about 55% of Kenya's population had electricity access, which included both urban and rural areas. Electrification, or the enabling of electricity access to people, is projected to reach over 90% of Kenyan homes by next year (EEAP).

B. Design

There are many existing coffee roasters and there is no need to start from scratch. There are a few important factors in making an effective coffee roaster provided by Enomoto Kazuo. A device needs to keep the beans in motion like a rotation blade to ensure that the beans will be evenly roasted and a heater to roast the beans. An exhaust opening to release the smoke, typically with a smoke filter. Temperature sensors will keep track of the temperature to ensure that the roasting is at a constant temperature. The container should be made up of a thermally conductive material like aluminum, because it will transfer the heat throughout the control volume (Kazuo). Cooling of the beans in a small sample batch (3kg) as used in this application can be cooled by hand in a basket or container. By examining the key components of a standard roaster, we can analyze and potentially design a roaster suitable for smallholder coffee farmers.

Section 3: Application

Smallholder coffee farmers will benefit greatly from an individually owned coffee roaster, but only if it is paired with a holistic approach to improve coffee profits that include realistic, affordable options to improve crop quality and a push towards providing premium coffee products. There is a great opportunity for smallholder coffee farmers in Kenya to benefit from the cash crop that is coffee, but farmers must be adequately prepared to deal with a market that only provides profits for premium products. Trainings aimed at financially realistic ways to improve production yields and quality are just as necessary as the technology and cost of the roaster. Farmers must be able to earn a livable income short term, while working to consistently produce premium quality coffee products long term. Time is important to consider, and improvements must be made soon before coffee farming is considered an unprofitable business among smallholder farmers. Though we are initially starting this project in Kenya for farmers in the Embu region, this coffee roaster could potentially be used in other parts of the world where smallholder coffee farmers are experiencing similar difficulties due to the low cost of coffee globally.

3. Methodology:

There should be a coffee roaster to recommend to the client for the farmers to use in practice. However, it cannot be any roaster, the roaster must satisfy certain conditions in order to be confidently recommended. The conditions were how well the roaster can remove chaff, which is the husk or dry skin of the coffee that comes off during the roasting process. It is important to remove the chaff to extend the life of the roaster, otherwise the chaff will build up and cause the roaster to malfunction. The roasters should be evaluated for how much they weigh since portability is important for the farmers. They will store the roaster until put to use on a monthly basis, so a lighter unit will better serve their needs. Other conditions are how much supervision is necessary during the roast, its durability, complexity, ventilation, and most important, cost.

To execute the evaluation, coffee roasters were purchased and examined to see the roasting options and how difficult it was to understand its operation. The roasters were then used to test out the quality of the roasts and how long it took to complete the roast. The roast process was repeated with varying amounts of beans to see the adaptability of the roasters.

Table 1: Evaluative Table

Objective	Unit	Target Value	Objective/ Subjective	How to Measure
Minimize Cost	$/roaster	$40 - $70	objective	Sum cost of materials
Minimize Complexity	Learning time	2 hr	subjective	Survey/usage test
Presence of Safety Features	Yes/No	Yes	objective	Presence of feature or not
Maximize Portability	Weight of roaster	10 lbs.	objective	Total weight
Maximize Chaff Removal	% of chaff removed from roast	<10%	objective	Weight of chaff inside vs removed

4. Results and Discussion

1. Coffee Roaster Evaluation

Initially, an Evaluative Table above (Table 1) of an ideal roaster was created using desired components as defined by the client. Then, a performance analysis of roasters on the market that fit these components was conducted. The desired outcome of the performance analysis was to see if an existing unit could meet the needs of the client, or could be modified to do so. Given the popularity of small-scale and home roasting, a functional solution seemed feasible using prior art. The results of the performance analysis are summarized in the Evaluative Matrix below (Table 2).

The three roasters that were compared were the West Bend brand air popcorn popper (Figure 2, Appendix), Barwell brand rotating coffee bean roaster (Figure 3, Appendix), and the

Probat small-scale coffee bean roaster (Figure 4, Appendix). The popcorn popper was chosen for its price and simplicity, and recommended by the UC Davis Coffee Lab (Kuhl). and other home-roasting resources (Sweet Maria's). The Barwell roaster was chosen for price, simplicity, and availability. The Probat was chosen based on the client's recommendation for a reliable, tested roaster.

Energy Source

Simpler, manual roasters heated by fire were researched, but found to provide highly variable product. Humans are not automated, thus a manually-rotated unit would not be the same process every time. Furthermore, fire is also an inconsistent heat source from roast to roast, and depending on the fuel, may impart different flavors to the coffee beans. Solar-powered units were also researched given Kenya's growing use of solar energy. Although several purveyors of coffee beans in the US and South America are beginning to use solar successfully to roast, the units are far from simple (Hadzig, et al). They are also large, heavy, and expensive. The units' permanent footprints and significant price tags are designed for businesses that roast on a much larger scale than the smallholder Kenyan farmers. As recommended by the client and corroborated by research on electrification in Kenya and the simplicity of existing electric roasters, the performance analysis focused on electric-powered units.

Performance Analysis

Each of the chosen roasters has its advantages and drawbacks. In order to draw conclusions on which model should be considered for use on coffee farms, the client's priorities must be reiterated: (1) price, (2) simplicity, and (3) consistency. To this, we added another priority, (4) safety.

Table 2: Evaluative Matrix of Three Commercial Coffee Roasters

	Price	Weight	Simplicity	Weight	Consistency	Weight	Experience	Weight	Safety	Weight	Total
Air Popper	5	3	5	2	3	1	3	2	3	3	43
Barwell	3	3	3	2	4	1	3	2	4	3	37
Probat	1	3	1	2	5	1	N/A	2	5	3	25

The primary hurdle for encouraging farmers to roast and taste their beans is the affordability of the machine. Thus, price was weighted heavily in the evaluative matrix above. The second hurdle is simplicity, since farmers will be more inclined to use the roaster if they can do so without a great deal of extra effort. Consistency of the roast is also weighed into the overall score, though not as heavily as price and simplicity. The reason is that the roaster will serve as a tool not just to evaluate quality, but also simply to help farmers gain a better understanding of their product. Consistency is therefore important and needs to be considered, but not as heavily as the two elements that cater more to the needs of the farmers. Safety is a necessary component of any consumer product that cannot be overlooked, especially for a product that is new and unfamiliar.

In terms of price, the air popper far out-performed the other roasters evaluated here, as well as other roasters that were researched and not specifically reported on. At $20 per unit, it provides an affordable option for farmers who may feel investing in quality control is too risky and may not provide any return. The Probat unit, though proven reliable for professionals, is far too expensive for the target stakeholders.

The simplicity of the air popper is also highest for the three roasters. Due to the nature of the fan used to blow the beans around to rotate them, there is one ideal weight of beans to use at a time (3oz). Additionally, there is only one temperature the unit operates at. As a result, the only variable users can change from roast to roast is time. This makes roasting extremely simple. From our experience, one batch of beans was done roasting in only 3 minutes, and all we had to do was press the “on” switch.

The Barwell unit is also fairly simple, though there are several variables in place that can be adjusted. The temperature controller has a wide range of temperatures (200-450℉) that is easily changed with an intuitive dial on the front of the unit. The drawback is it is difficult to know exactly when the target temperature is reached. A range of weights of beans can be roasted at once (4-24oz), and the stirring mechanism still effectively rotates and turns the beans so that all of them are roasted evenly. Time is another variable in the Barwell roaster, decided by the user. Though the controls on the Barwell are fairly simple to operate, the number of combinations of times, temperatures, and amount of beans is already exponentially larger than the air popper due to the choice of 3 variables over 1. For users interested in experimenting, this may be a plus, but for users brand new to roasting, it may over-complicate the process.

The Probat roaster is a larger unit designed to mimic large-scale production models. Like the Barwell, it has variable temperature (flame control), bean amount, and time. Although it has the same variables as the Barwell unit, it is much larger and more mechanically complex. This would require the user have a higher level of expertise for fixing it if something needed repair. The professionals that use them likely have access to technicians that can service the machines--access that smallholder farmers may not be able to get or afford.

Consistency in performance and product output is a necessary component for the roaster. This allows farmers to check the consistency of their product from harvest to harvest, and potentially observe changes in flavor if there are changes in agricultural practices implemented. However, from speaking with our client, we learned that the roaster would only be used by farmers on roughly a monthly basis. Since roasting will be performed infrequently and with a small quantity of beans, consistency of the unit is a lower priority need compared to users that roast commercially at a large scale. The Probat unit is a tried and trusted roaster in the industry for this reason. The Barwell and air popper units were fairly consistent in their performance, though tend to differ slightly if several batches are roasted in a row as they become hotter. We noticed with the air popper, for example, that our first batch when the machine was starting from ambient temperature took about 3 minutes 15 seconds, and a later batch when the machine had roasted several batches and was still warm took only 2 minutes 50 seconds. This is not a huge amount of time, but when a batch roasts in only about 3 minutes, a difference of 25 seconds is fairly significant. This inconsistency in timing highlights the importance of training users to recognize other sensory cues such as color, smell, steam, and cracking sounds (Figure 5, Appendix). Another source of inconsistency in the air popper was coffee bean amount. Accidentally adding slightly too high or too low of a weight of coffee beans meant the fan that moves them around could not operate optimally. This led to batches of beans with a range of roast levels, some scorched and some under-roasted.

The experience score took into account our overall impression of using the roaster. The air popper was easy to use, but the design of the lid resulted in many of the beans and chaff flying out due to the airflow of the fan. A modified screen over the popper kept the beans in, but the chaff still flew out of the machine and left a lot of debris scattered around. This may be less of an issue if the roaster could be used outdoors.The air popper also heated up rapidly, leaving less room for error for inexperienced roasters like ourselves. There was a small window of time between the beans going from roasted to burnt. The opening into the air popper was a small circle a few inches in diameter, which allow a moderate peak into what the beans looked like; cracking and smoke were the primary signs that they were ready. The Barwell roaster had no chaff removal mechanism, which meant it would have to be separated manually following roasting with a screen or water, or not at all by the user. The wide heating surface and clear lid meant we could easily view the beans as their color progressed. However, once they heated up to the point that they were steaming, the glass lid became foggy, so the it still had to be removed to clearly see them. Both the Barwell and air popper units required users to remove beans into a different container for cooling once the roasting finished. The Probat has built-in cooling mechanisms, but with such a small quantity of beans being roasted, simply shaking them in a vented bowl or colander is sufficient for the small-scale users. We must acknowledge that the "experience" score was largely subjective, and therefore biased towards our personal needs in a coffee roaster. This emphasizes the need have many people test future prototypes and get feedback from the farmers that will ultimately use it.

Based on research and other users' experiences found in online forums, it became clear that a safety category should not be overlooked (Sweet Maria's). Shortcomings in electronic devices can cause sparks which are a fire hazard, and working with something that heats up rapidly to 400℉ or higher brings its own set of necessary safety precautions. Although the air popper's rapid heating was convenient and significantly reduced the roasting time, such a feature may cause safety issues if not managed. Some users reported certain air popper models could actually cause fires if left unattended or not allowed proper ventilation. We did notice that if the popper overheated it would not turn on until it cooled down, but if the vents became clogged with chaff or other debris, it could easily overheat after only a couple of roasts. This problem was simply solved by cleaning out the vents each time we roasted, but would be more convenient if vents were less easily clogged. Adding too many beans to the air popper at a time also can cause scorching because they are too heavy for the fan to rotate them. This is solved by the popper by marking a "MAX FILL" line inside the roaster that is easy to see. The Barwell roaster had several features that made it a little more safety-conscious for users. Handles on the exterior of the unit allowed users to pick up the machine, even when it was hot, without getting burned. The lid also had a plastic handle whose material was insulated so users could lift off the lid during roasting. The heating element also heated more gradually than the air popper.

2. Coffee Processing Quality Control Research

In addition to researching existing coffee roasters, we also looked into coffee processing practices that could positively contribute to increasing farmers' coffee quality. Changes to agricultural practices may only lead to small changes in bean quality that take a while to notice and are difficult to detect in brewed coffee. Moreover, purchasing pesticides or fertilizer may be out of scope for some farmers due to budget constraints (Karanja, et al). Practices during processing, however, can have more noticeable impact on the quality of coffee, and lead to higher prices. The International Coffee Organization has guidelines describing the standards of different coffee qualities. These standards are based on the number of discolored beans in a 300g sample. Other organizations' grading guidelines follow similar standards based on bean color. Thus, if farmers can reduce the number of discolored beans they have in a batch, they can increase the price they sell their product for. Farmers could potentially have two grades of beans they could sell, one high-grade with all bad beans removed, and one lower-grade with some imperfect beans included, and fetch a higher overall price than if the two grades were combined.

The coffee flowchart (Figure 6, Appendix) details the steps of coffee processing from picking the cherries to bagging the green beans (Sucden S&D). Depending on the farm, they may sell beans at various steps in the process. Some sell the whole fruit right after harvesting, while others sell the dried beans, and still others perform the whole process and sell green beans. The level of processing depends on the equipment, knowledge, and labor available. This flowchart illustrates one step towards the end of the process where sorting may occur, right before bagging. But farmers may be able to perform sorting at several additional steps. Because coffee harvesting is done by hand on small- to moderate-sized farms, laborers can be trained to pick out imperfect beans. Workers are often paid by the pound, so they should save the imperfect beans and receive the same pay for the overall weight of beans they picked. Some farms provide red bracelets that harvesters can use to match the color of perfectly ripe fruit. Coffee cherries that do not match the bracelet are left on the tree. Another sorting step can be done after picking by putting the cherries in water and removing any fruit that floats. Floating indicates that the bean in the middle is small or underdeveloped. Finally, workers can inspect beans during the drying process and again do a sweep to remove discolored, misshapen, or broken beans. During drying, beans must be regularly stirred to insure even drying. This would be a good time to concurrently check for imperfect beans and remove them (Molina). A visual guide to coffee bean defects details the types of beans that should be removed (Figure 7, Appendix) (Toper NK).

5. Recommendations

After evaluating the roasters, the “Air Crazy Popcorn Popper” is the most feasible option due to its low cost. In its current state, the roaster still needs some modifications. We recommend to continue this project in D-Lab 2 to build a functioning prototype for the farmers to test out. The lid needs to be changed because beans blow out through the current one, so the new one needs to be more secure. As recommended from *Sweet Maria’s* website, a popcorn roaster should have the hot air enter through the side and the bottom should be solid as shown in Figure 1. The current roaster is the opposite, so that needs to be changes. Also the chaff remover needs to be more controlled, as of now the chaff comes flying out through the top. Further designs will incorporate a method to catch the chaff which can also be incorporated with the lid designs. Additionally, if the design of the final roaster is not manufactured and simply a modified existing popcorn popper/roaster, more research should be done to ensure that the brand of roaster is available locally in Kenya. Benefits of a local roaster would be lower cost and the potential to repair locally.

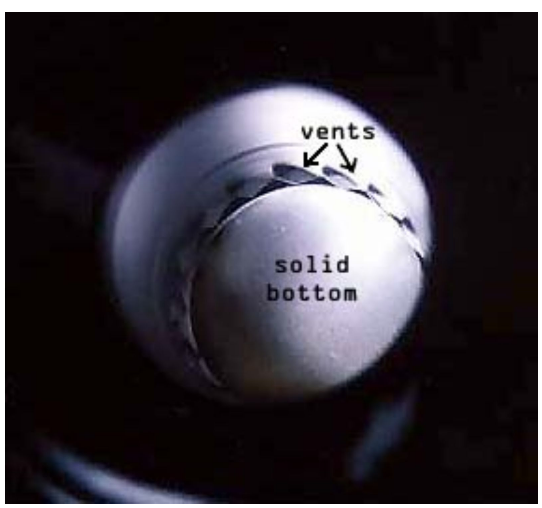

Figure 1: Interior design for popcorn roaster. For effective roasting, the vents are recommended to be placed on the sides.

In addition to the the roaster, education on the importance of sorting is recommended. It is important to emphasize to the coffee farmers to keep the ripe beans separated from the unripe ones. The quality control section in the discussion goes more in depth about its importance.

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7. Appendix

Figure 2: The West Bend Air Crazy Air Popper

Figure 3: The Barwell Roaster

Figure 4: The Probat Sample Roaster

Figure 5: Color change of beans during roasting is the most prominent visual cue

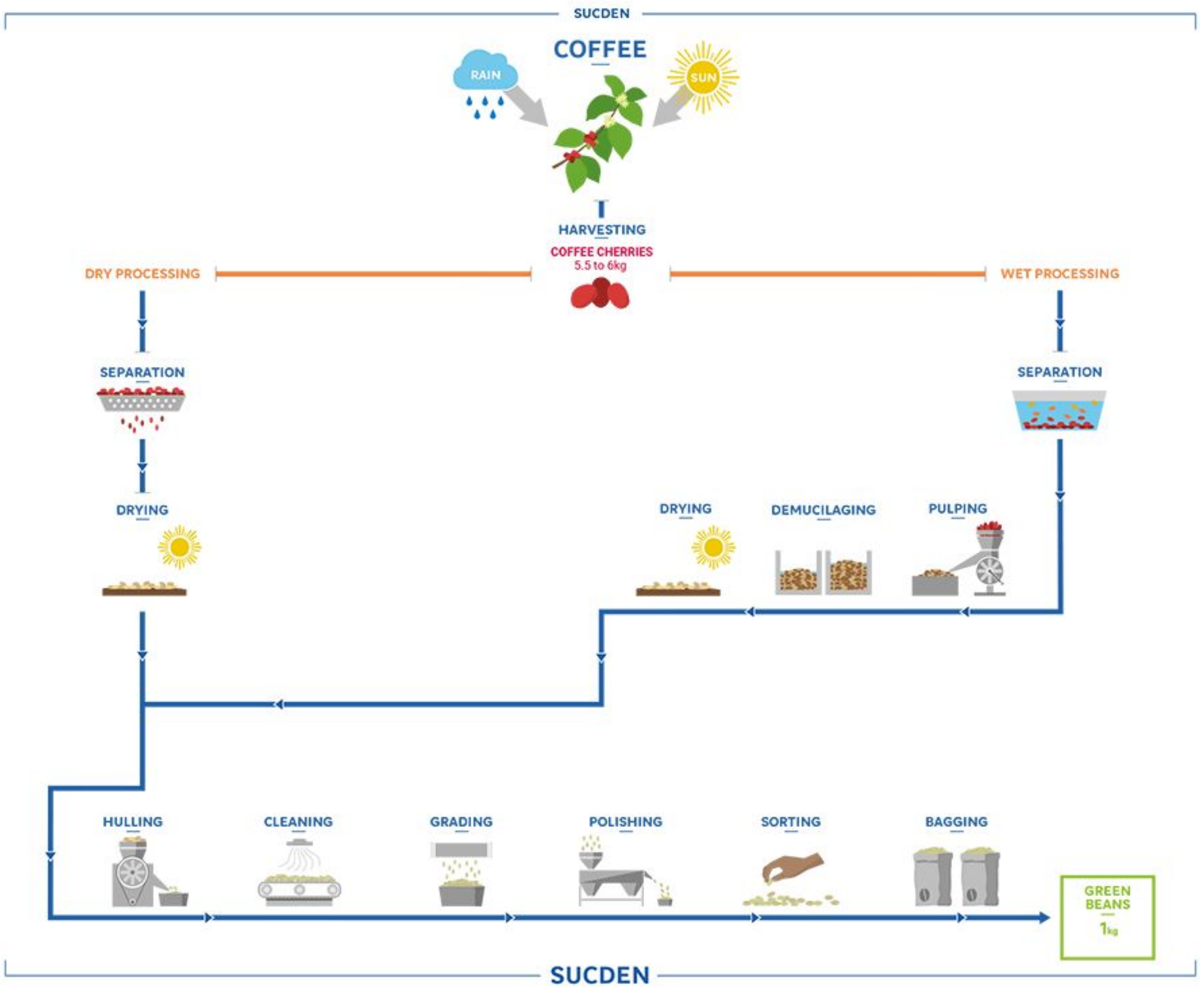

Figure 6: Coffee Processing Flowchart. Quality control steps include at harvest, wet processing separation, drying, and sorting.

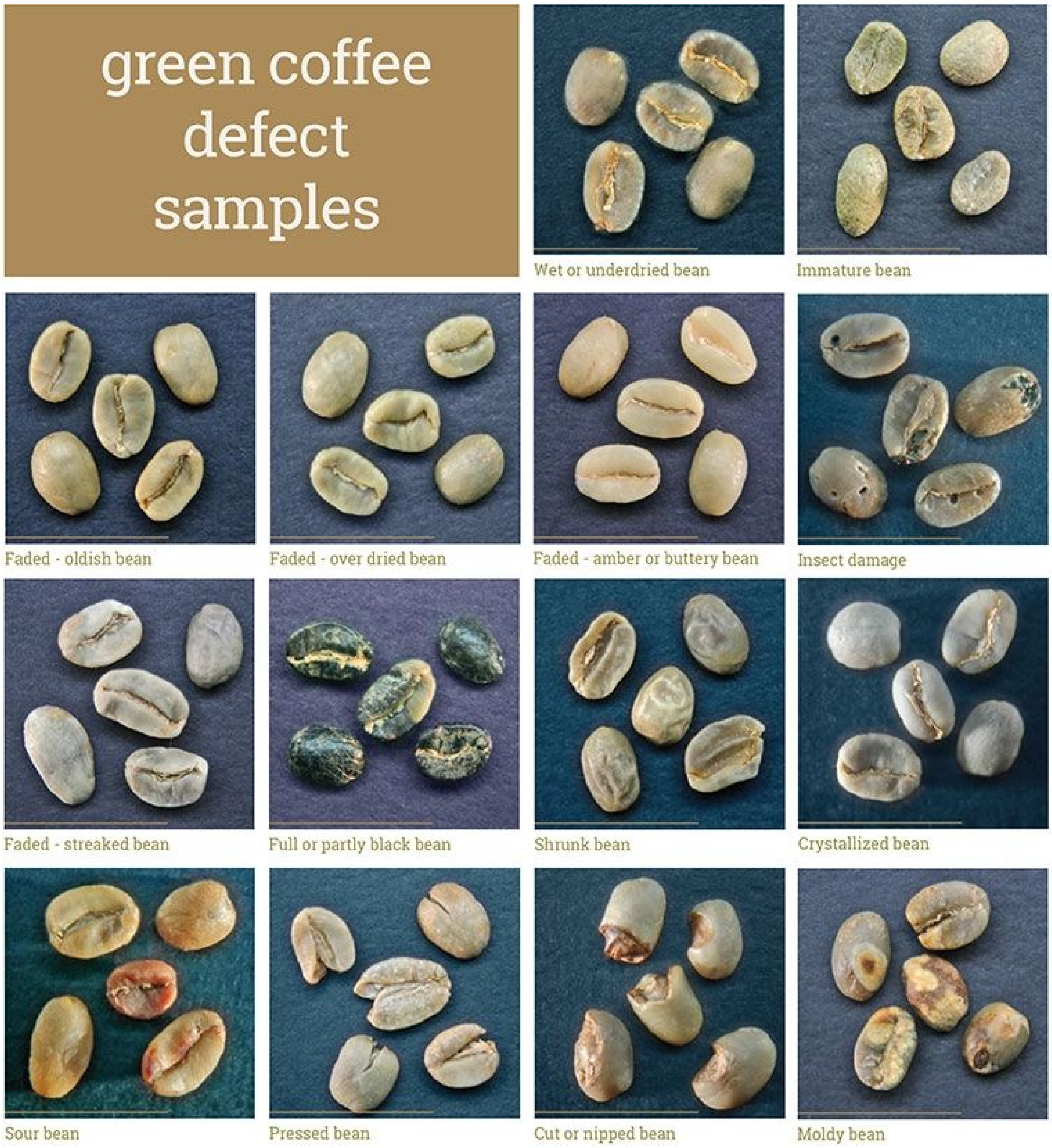

Figure 7: Common Green Coffee Bean Defects.