Documentation and Analysis of Avocado Oil Extraction Technologies in Leguruki, Tanzania

by

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ABSTRACT

A team of MIT students and researchers as well as a local team in Leguruki, Tanzania has been working on extracting oil from excess supplies of avocados since 2014 with the goal of adapting oil extraction methods to small-scale farmers. Through this process of extracting oil, the team has explored several iterations of avocado dryers, presses, and centrifuges. Analyzing this machinery has given a broader picture of the commonalities and requirements of the designs. A set of evaluation criteria can be extracted from this analysis. Having these guidelines in place for future designs for oil extraction will streamline and aid the process, facilitating the small-scale production of avocado oil, and eventually augmenting the incomes of small-scale farmers.

Thesis Supervisor: Amy Smith

Tile: Documentation and Analysis of Avocado Oil Extraction Technologies in Leguruki, Tanzania

Acknowledgments

The work performed on avocado oil extraction has truly been a team effort. I want to thank all the present/previous members of Voca (Brandon Benson, Ellie Klose, Charles Vitry, Kate Tatar, Julia Rue, Dana Levin, Ruth Park, Amna Mazgoub), Avomeru (Eliot, Jesse, Iggy, Tristan), everyone in the D-LAB shop, and all of AISE/TWENDE, as well as everyone who so warmly welcomed Voca in Tanzania. Of course, I would like to thank our fearless leaders, Elizabeth Hoffecker Moreno and David Saleh, as well as the MIT D-Lab for being so supportive throughout this process. We have also received a tremendous amount of support from MIT IDEAS, Keely Swan in particular, and from the Global Center for Food Systems Innovation. Thank you all for this wonderful experience.

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1. Introduction

Although there has been significant recent economic growth in Tanzania, 34% of Tanzanians are below the income poverty line and the basic needs of up to 57% of the total population are not met [1]. Agriculture is a main industry in Tanzania, employing 75% of the labor force and contributing 26% of the country's GDP. An estimated 31 million people, over 60% of Tanzania's total population, are smallholder farmers, dominating the agricultural sector [2]. In addition, the value of many tree crops is determined by their shelf life. Tree crops have an exceptionally short shelf life; in particular, the shelf life of avocados is less than five days after ripening. Short shelf life combined with a concentrated harvesting period leads to a great loss of value in tree crops.

In Tanzania, avocados are present in excess. Although avocados are not a main cash crop in Tanzania, they are very much prevalent throughout the country, as avocado trees are often used to shade coffee plants, a main export of Tanzania. The seasonal abundance of avocados in addition to their short shelf life leads to little demand for avocados on the market and over half of the avocado crop rotting on the ground or being fed to livestock, not using avocados to their full potential value. There are several ways to add value to avocados; avocados can be incorporated into soaps, creams, teas, and certain medicinal uses. One value-adding method that is currently being pursued in the rural ward of Leguruki, Tanzania is to extract oil from avocado flesh. By taking advantage of the excess avocado crop in Tanzania and aiding farmers in extracting avocado oil, it is possible to help augment the incomes of small-scale farmers. This oil extraction technology can then be applied to other developing countries with similar circumstances.

The process of avocado oil extraction is complicated, often requiring five or more steps and three or more different types of machinery [3]. Analyzing and learning from the different types of technology used in Leguruki's avocado oil extraction process can inform a set of criteria necessary for oil extraction. In future developments of similar technology, this set of criteria can be used as baseline requirements for success, helping to guide the design process.

Although this thesis follows avocado oil extraction research in Tanzania and at MIT, this process is being pursued in several different countries, including Chile, Columbia, Argentina, Kenya, Tanzania, and the United States, proving to be a prevalent problem that could be applicable in several areas beyond East Africa [3].

2. Background

The background will be divided into two sections: the benefits, uses, and market for avocado oil (Section 2.1), and a brief overview of the oil extraction process in Leguruki, Tanzania (Section 2.2). While a brief overview of the technology will be given in Section 2.2, a more detailed description of design, results, and analysis will be present in Section 3.

2.1 Benefits, Uses, and Market for Avocado Oil

Avocado oil can be used for both cooking and cosmetics. The avocado flesh of one avocado contains 20% of the daily-recommended value of Vitamin E and Vitamin C, and well as 40% of the recommended amount of Vitamin K, and contains several monounsaturated fats. In addition, avocado oil also has a smoke point above 250°C which makes it a better oil to use when cooking, especially frying, in comparison to traditional sunflower, canola, or vegetable oil [4]. In the cosmetic industry, because the healthy fats present in avocado oil is similar to those the human body naturally produces, avocado oil is used because of its high skin penetration and rapid absorption [4]. Avocado oil can be incorporated into soaps, creams, and other cosmetic products, but in Tanzania, it is common to directly apply oil to hair and skin. To extract cosmetic grade avocado oil, avocado flesh cannot, at any point in the process, be heated above 50°C. Above 50°C, many of the healthy fats and vitamins begin to break down and the oil loses its ability to be rapidly absorbed into skin. However, looking at the market for cooking and cosmetic oils, the market price for cosmetic oils is around 20 times the value of cooking oil; on the markets in Arusha, Tanzania, cooking oil (usually sunflower seed oil) sells for around 3,000Tsh/liter (~$1.50/L) whereas cosmetic oil sells for 60,000Tsh/liter (~$30/L). Because of the significant profit margin, the teams (Avomeru, Voca) working on avocado oil in Leguruki have largely focused on producing cosmetic grade avocado oil.

The essential oil market is rapidly expanding on a global scale, as consumer awareness regarding health benefits of organic products grows. By 2022, the global essential oil market is expected to reach 11.67 billion USD. This growth in market brings with it several businesses that have its roots in supporting small-scale farmers in the developing world [5]. For example, MoringaConnect is a beauty and health startup that helps improve small-scale farmers' living and working conditions in Ghana by creating new jobs processing moringa seeds into cosmetic grade essential oil [6]. Similarly, Lush, a global seller of fresh handmade cosmetics that incorporates many essential oils and other organic ingredients in their products, places an emphasis on ensuring good working conditions for their suppliers in developing countries [7]. The emerging essential oils market has been a way for small-scale farmers to bring natural products indigenous to their countries to produce to a global market, improving their everyday incomes and standards of living.

2.2 Context of Oil Extraction Development in Leguruki, TZ

This section follows the design journey experienced by the oil extraction team working with small-scale farmers in Leguruki, Tanzania, separated into 4 different phases.

2.2.1 Phase 1: Ideation (IDDS)

IDDS (International Development Design Summit) is an intense, multi-week collaborative design experience, now overseen by MIT's IDIN (International Design Innovation Network).

Each summer, designers, inventors, and entrepreneurs from all over the world and walks of life come together for a month to work on design challenges in different communities. In 2014, an IDDS was held in Arusha, Tanzania, a city in northern Tanzania where representatives worked with local farmers to identify potential design ideas. The farmers suggested working in Leguruki, a nearby rural ward, to create value from their excess avocado crop. And so, the idea of extracting value from excess was born and the IDDS team began to explore the process of avocado oil extraction. Being able to use avocado oil for cooking or for selling for cosmetics could greatly augment farmers' incomes with avocados that were previously not used to their full potential [8].

Working under the constraints of this month long summit, the participants pursued the method of oil extraction by drying and pressing. Drying the avocado removes water content, and pressing the remains will result in oil. During the summit, teams explored four different designs for avocado presses, but were not as successful in the drying process [8].

2.2.2 Phase 2: Iteration on Drying and Pressing

After IDDS, certain community members continued to pursue the avocado oil project on their own. In particular, Penuel, a barber from Tanzania very interested in engineering, continued to explore different types of presses and built his own prototype, a linear screw jack press. Meanwhile, Pastor Emmanuel, interested in starting an avocado oil business for his co-op of farmers, performed several tests in drying avocados of different ripeness and sizes.

The avocado drying process was pitched to a group of students taking D-Lab Development, a class at MIT focusing on appropriate technologies in the developing world, in Fall 2014. The students of this team proceeded to research and build a solar dryer (Dryer Prototype 1.0) before traveling to Leguruki to build a second dryer with the input of local community members (Dryer Prototype 2.0).

In Tanzania, the MIT D-Lab Development team performed some market research, traveling to farmers markets, cosmetic stores, and supermarkets to find potential buyers and prices for avocado oil. While speaking with cosmetic producers, the MIT team learned that cosmetic grade avocado oil needed to be cold pressed— produced under 50°C. Seeing the price gap between cosmetic oil and cooking oil, the team determined that it was necessary to explore other, cold press processing methods. [9]

2.2.3 Phase 3: Exploring Alternative Methods: Centrifugation

Because cosmetic grade oil needs to be produced under 50°C, a pivot occurred in both the design process of the local Tanzanian team and the MIT team. Most industrial avocado oil extraction is performed by large-scale centrifugation, so both teams began to explore small-scale centrifuges in an attempt to replicate the effects of industrial machinery in smaller form. The Tanzanian team, Avomeru, iterated through two centrifuge designs: Hand Drill Centrifuge and Vertical Centrifuge. Meanwhile, the MIT team, Voca, competed in the MIT IDEAS Global Challenge, winning $5,000 in order to pursue a small-scale centrifuge prototype. Voca performed several baseline tests with existing lab centrifuges and iterated through three different designs of centrifuges: Horizontal Centrifuge 1.0, Horizontal Centrifuge 2.0, and Spin Dryer Centrifuge.

2.2.4 Phase 4: Oil Extraction to Market

Through this testing, it was determined that small-scale, low-cost centrifugation is not an easily achievable path. Instead, the Avomeru team decided to pursue a known method of oil extraction, learned from Twahir Nzallawahe, an agricultural director in Dar es Salaam running an avocado side business. The D-Lab Development team originally learned about Nzallawahe during their trip and visited him, learning about his oil extraction method of using additives, pressing, and filtering. This information was then relayed to Avomeru who reached out to Nzallawahe for advice, leading to successful oil production. In order to aid Avomeru in developing their brand, Voca applied to and received a $10,000 grant from the Global Center for Food Systems Innovation (GCFSI).

Since successful oil extraction has occurred in Leguruki, Avomeru has transformed into a start up. After focusing on packaging and branding, the team has begun selling at local farmers markets every weekend. Avomeru is currently working with 28 different farmer co-ops in oil extraction. Avomeru gives the farmers the machinery necessary for oil extraction and then buys the oil back from them and performs all refining, filtering, and pasteurization so that quality stays relatively constant. Avomeru then bottles and sells the oil at farmers' markets in Arusha and to small-scale, organic cosmetics producers. Right now, Avomeru is buying oil from farmers at 20,000Tsh/liter and selling the processed oil on the market for 60,000Tsh/liter.

Comparatively, Nzallawahe owns an avocado plantation, comparable to a village of avocado trees. He sells 700L of avocado per harvesting season (twice a year), using similar oil extraction methods that should result in similar oil yields. At 20,000 Tsh/liter going back to the farmer and 28 co-ops, each co-op would receive roughly 1,000,000Tsh/year (~$450/year).

3. Design Analysis

This section will focus on the design, testing results, and learning of the different technologies used throughout Avomeru and Voca's processes. Because most testing was performed on the field or during design iterations, the technologies are tested to different extents.

3.1 IDDS Presses

3.1.1 IDDS Presses: Design

During IDDS, the Avocado Team prototyped 4 different presses, a jack press, a standing press, a lever press, and a hammer press (Figure 1). Each prototype was made by welding together steel extrusions [9].

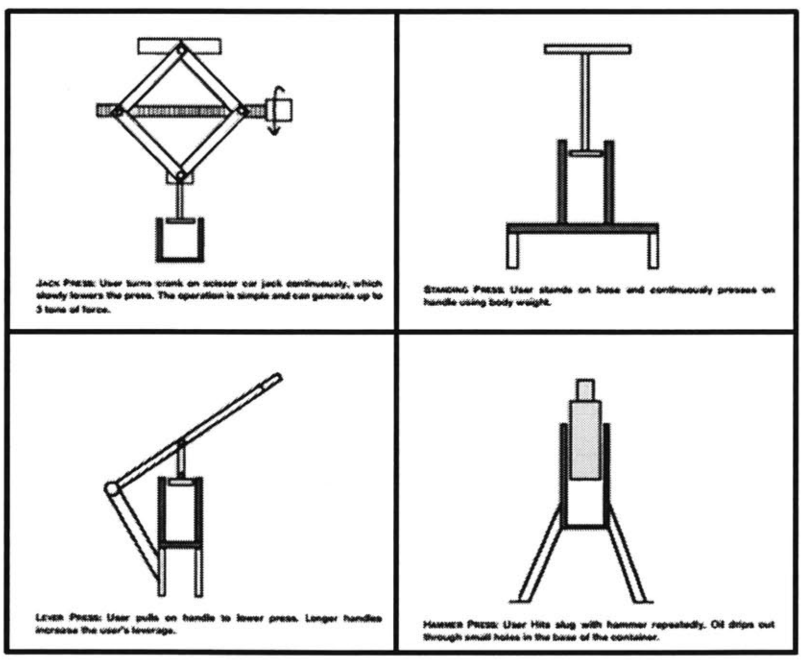


Figure 1: IDDS Press Schematics The four presses (jack press, standing press, lever press, and hammer press) are shown. These four designs were built and tested by the IDDS avocado team [8].

3.1.2 IDDS Presses: Results

Each press was tested with avocado mash that had been dried in the sun on a tarp. The IDDS avocado team chose to judge the presses based on the quantity of oil extracted, the time it took for oil to be extracted, how user friendly the design was (easy to clean, learn to use, operate), and the cost, shown in Figure 2. These designs and tests explored several different avenues.

Press	Quantity Extracted	Extraction Speed	User Friendliness	Cost
Standing	0	0	0	0
Hammer	–	0	–	0
Jack	++	–	++	– –

Note: Lever press not included due to insufficient time for testing

Figure 2: IDDS Press Pugh Chart Pugh chart comparing 3 press prototypes created during IDDS [8].

3.1.2 IDDS Presses: Learnings

Although a final prototype direction was not chosen at the end of IDDS, the process proved viable to continue post-IDDS. The press prototypes were successful, to varying degrees, but would prove possible. However, the drying process is a bigger challenge

3.2 Peneul's Press

Using the IDDS prototypes as a basis, Peneul, a participant of the avocado project from Leguruki, went onwards to design and build his own press.

3.2.1 Peneul's Press: Design

Post IDDS, Peneuel continued to work on presses, constructing his own design of a jack press. The drying process he developed consisted of peeling, de-pitting and mashing the avocado, and spreading it into a thin layer on the roof of a house. Although effective under the Tanzanian sun, drying on a roof did not prove successful on overcast days and the avocado was not protected from animals or insects.

Penuel's press consisted of a linear press actuated by a screw crank. The press pushed dried avocado through a mesh layer, allowing oil and some small particles of avocado to seep through.

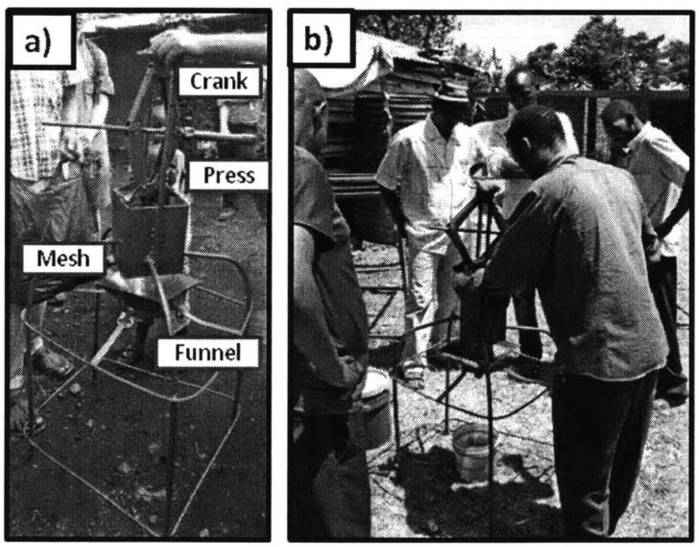


Figure 3: Peneul's Jack Press Post IDDS, Peneul, a barber from Leguruki, created his own avocado press, using the press on sun-dried avocado mash. a) As the user turns the crank, the diamond shaped bars expand, lowering the press and exerting force on the avocado. Avocado mash is pressed against them mesh,

allowing only oil to seep through to the funnel and land in a bucket that would be placed beneath. b) Penuel demonstrating how the press is used.

3.2.2 Peneul's Press: Results

Peneul successfully used his press to extract 5 liters of oil prior to the D-Lab team's arrival. Although the rate of extraction was never measured, by estimation, 1 liter of oil could easily be extracted using Peneul's press in an hour. Dried avocado pulp could be passed through Peneul's press twice before oil yield became negligible. Afterwards, the dried, pressed pulp was used as fodder for livestock. The oil, however, was left outdoors in the open air and began to smell rancid. Peneul's press seemed fairly sturdy but as time passed and large forces were continually exerted on the press, the diamond shaped bars of the press began to bend under stress.

3.2.3 Peneul's Press: Learnings

Peneul's press proved the possibility of extracting a significant amount of oil using the drying and pressing method, although press fatigue under repeated cycles of use was an issue. His own innovation also represented the continuous interest of local community members in Leguruki and their capability to design and build. The oil he pressed also brought to attention the lack of understanding regarding filtration and pasteurization, which would prevent the oil from oxidizing and becoming rancid.

3.3 Solar Dryer 1.0 (MIT)

After researching the topic in Cambridge, the D-Lab team designed a built a prototype of a solar dryer, pulling aspects of existing dryers from different forms. The goal of this prototype was to gain experience constructing and to learn more about the components of a solar dryer.

3.3.1 Solar Dryer 1.0 (MIT): Design

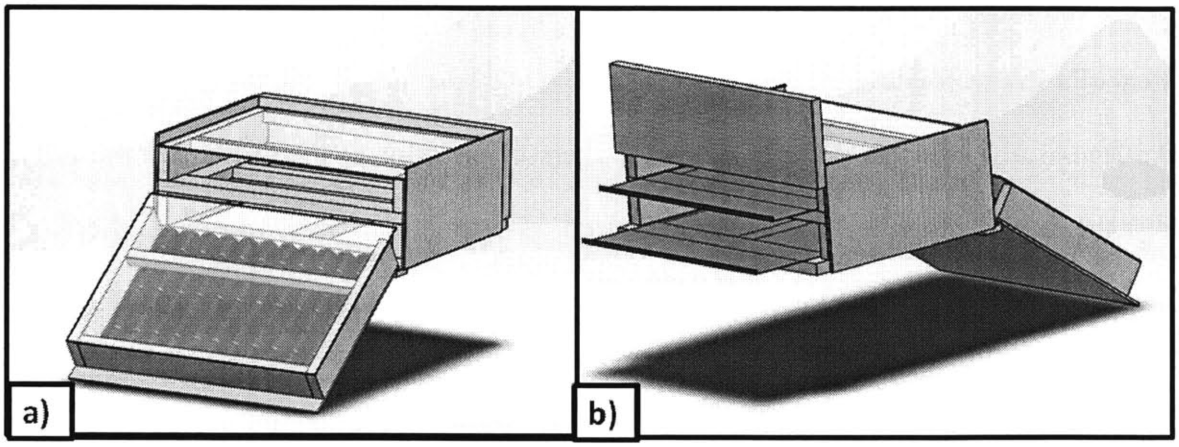
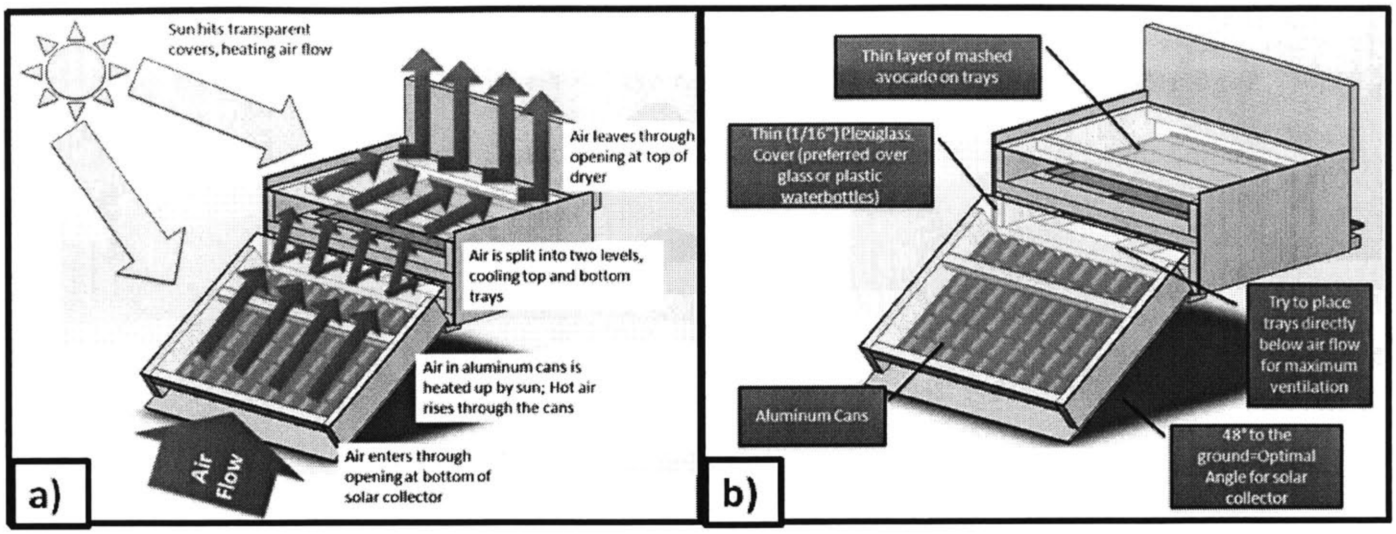


Figure 4: 3D model of Solar Dryer 1.0. a) Dryer consisted of two parts, a solar collector full of aluminum cans and a box with two shelves for avocado mash. b) For maintenance and ease, the back of the dryer slides up, exposing two plates that can be easily removed and reloaded with fresh avocado. Note: actual solar collector was extremely similar to this model.

The design consisted of two parts: a solar collector and a shelving box. The shelving box consisted of a wooden box with shelves, attached to alternating sides such that the airflow zigzagged up. The top of the box was covered in Plexiglas except for a long opening on one side, allowing the sun to warm up the air, which would escape through the opening at the top. The box sat on plastic 5 gallon buckets (not shown), elevated such that the solar collector was sloped and attached to the bottom of the box.



The solar collector consisted of a thin wooden box, also covered in Plexiglas. Inside the box, rows of aluminum cans were cut into tubes, painted black, and glued onto the bottom of the box. Because several existing designs for insulation and heating units in developing countries use boxes of aluminum cans, Voca pursued this method to maximize heat transfer in the solar collector. To compare the amount of heat contained by different materials, a short experiment was first performed to verify the effectiveness of the aluminum cans. Several small boxes were constructed with different bottoms—wood, steel, and aluminum cans. After being placed under heat lamps for an hour, the air in the aluminum cans was much warmer than that in the other boxes, and aluminum cans were chosen for the design.

The concept behind the solar dryer was that the air inside the aluminum cans heats up, and because warm air rises, travels up the incline of the solar collector, enters the shelving box and flows over the trays, alternating flow direction as the air rises through the opening at the top.

To use this dryer, avocado would be depitted, peeled, and mashed, then spread onto trays which could be inserted into the dryer through the back (Figure 5b).

Figure 5: Diagram of Solar Dryer 1.0 a) Detailed description of the principles behind the design for this solar dryer. b) Detailed description of materials and components of this dryer.

3.3.2 Solar Dryer 1.0 (MIT): Results

The solar dryer was not tested with avocado, as weather did not permit; winter in Boston is not conducive to solar drying. However, temperatures were still taken while the solar collector was exposed to heat lamps in order to understand the effects of the solar collector. Using two thermocouples, one placed at the bottom, where it is open to the air, of the solar collector and one at the top, where it connects to the shelving box, data was collected for 18 hours. A net difference of about 10 degrees Fahrenheit was observed while the solar collector was exposed to one heat lamp of ~250W over eight hours (Figure 7) [10]. However, because the dryer was not tested with avocados, the temperature gradient could be very different in the field. The evaporation of water in the avocado would reduce the temperature gradient.

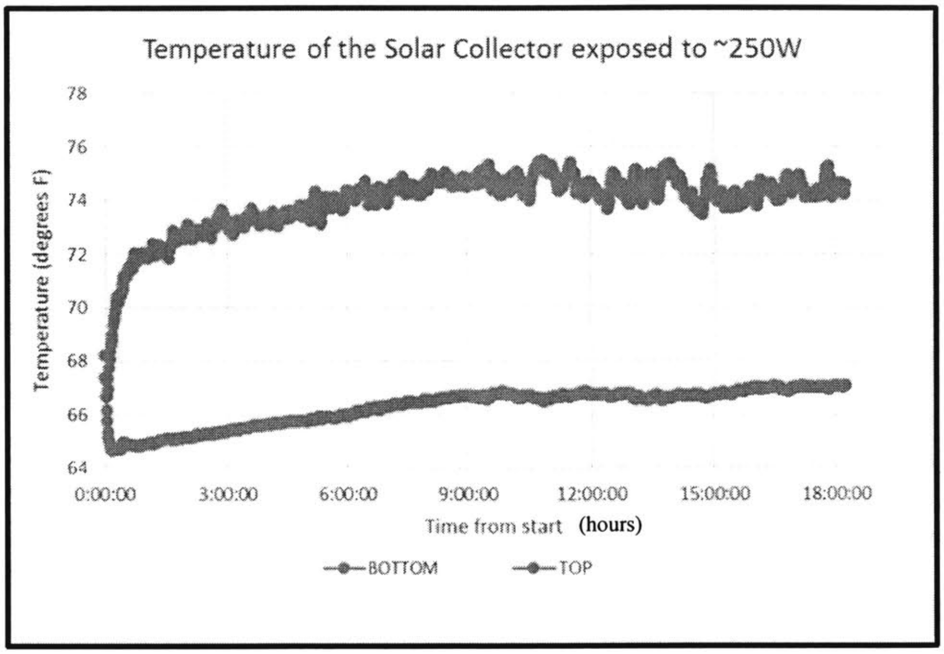


Figure 6: Results of temperature change from experimentation on Solar Dryer 1.0 There is a clear increase in temperature as time passed, almost a 10°F increase in temperature. Under more sun, especially in near the equator in Tanzania, the effects would be expected to be magnified. However, avocado was not included in the trial, which could reduce the temperature gradient [9].

3.3.3 Solar Dryer 1.0 (MIT): Learnings

Although testing was not performed with avocados, there was still much to be learned from this prototype. First and foremost, the prototype allowed the team to become familiar with solar dryer designs and construction. In addition, the solar dryer proved that taking advantage of warm air rising is valid for airflow. However, the design pointed out the need for a fairly airtight design (warm air could be felt leaving the gap between solar collector and shelving box).

3.4 Solar Dryer 2.0 (Leguruki)

In Leguruki, the team of MIT students redesigned the solar dryer taking into consideration the constraints of local materials, transportation (the dryer needed to be able to movable by car), and the design input of the local community partners.

3.4.1 Solar Dryer 2.0 (Leguruki): Design

The design consists of a tunnel dryer, a base with a clear tarp on top forming a tunnel, tilted at an angle with several mesh trays inside holding avocado mash. The design consists of a clear, plastic sheet that covers the dryer, a wooden base stood at an angle containing two trays of avocado mash and a steel plate painted back attached to the bottom of the dryer. The clear plastic cover took advantage of the green house effect, trapping in the heat from the sun, raising the internal temperature of the dryer above ambient temperature. The tunnel dryer is at an angle, to promote airflow through the tunnel as the air rises through tunnel dryer while it is being heated, facilitating ventilation upwards, and out of the dryer. The sheet of steel at the entrance of the dryer was intended to help heat the air that enters, as the metal should heat up more than the surrounding air, painted black to maximize absorption. Mesh covers both entrances to the tunnel, in order to keep out pollutants, insects and animals. In Leguruki, two tunnel dryers were built, one that included a chimney. The rising hot air in the chimney created a pressure difference, drawing air up through the chimney, facilitating ventilation [9].

To use this design, trays were removed, avocado mash spread thinly onto the trays, and returned to the dryer for about 4 hours. When testing, the masses of squares of mesh on the trays were weighed to determine how much water had evaporated.

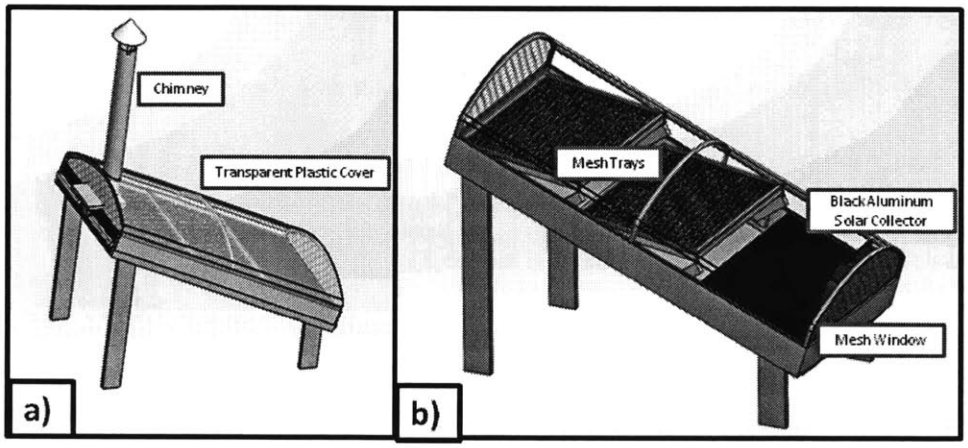


Figure 7: 3D Model of Solar Dryer 2.0 a) Outside view of Solar Dryer 2.0 b) Looking at an inside view of the trays, without tarp.

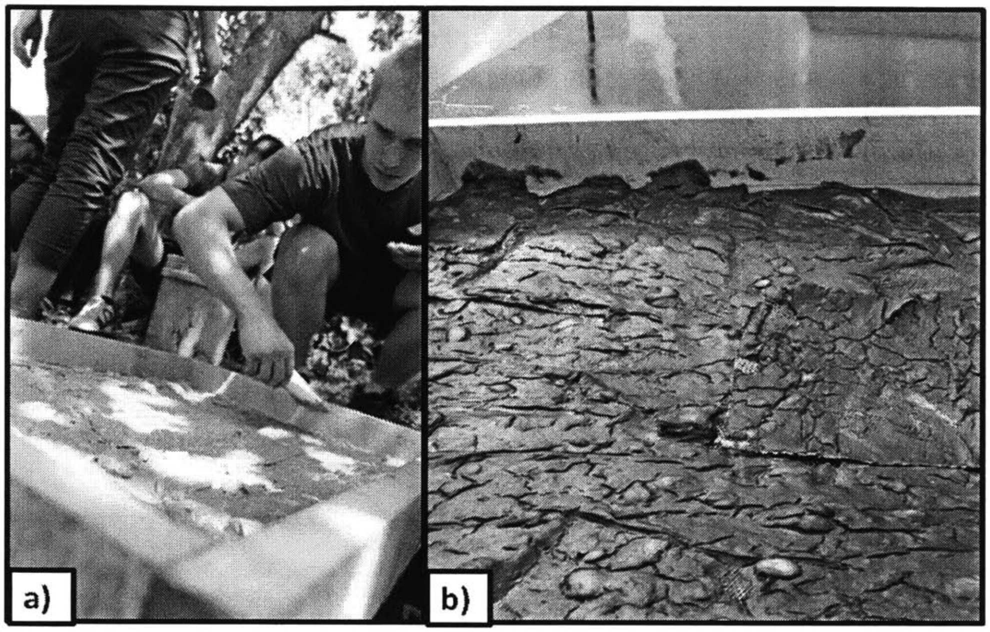


Figure 8: Drying Avocado Mash Avocado mash was thinly spread onto the mesh trays. In the picture on the right, you can see the dried avocado but also the imprints of the squares of mesh used as samples. Masses of squares of mesh were measured to calculate percent mass decrease throughout the drying process to track the efficiency of the dryer.

3.4.2 Solar Dryer 2.0 (Leguruki): Results

This particular experiment was performed on a sunny summer day in January. Preparation of avocado mash consisted of peeling and de-pitting avocados into buckets, which were then mashed together using a large stick and thinly spread on mesh trays. One can see in Figure 10 that the tunnel dryer did not make a significant difference in the percent mass loss, or water loss, in the avocado mash until later on in the afternoon. This leads us to believe that although just sun-drying on a tray on the ground could be nearly as efficient as the dryer, the dryer will be able to perform better on overcast days. The dryer also offers sufficient protection from the elements, animals, and other potential disturbances. Repeated opening and closing of the plastic tarp and removal of mesh squares could have caused error in data.

Of the two dryers built, only one dryer included a chimney. Although data was only taken on the dryer without the chimney, there were no noticeable differences in the results of the dryer with the chimney versus the one without.

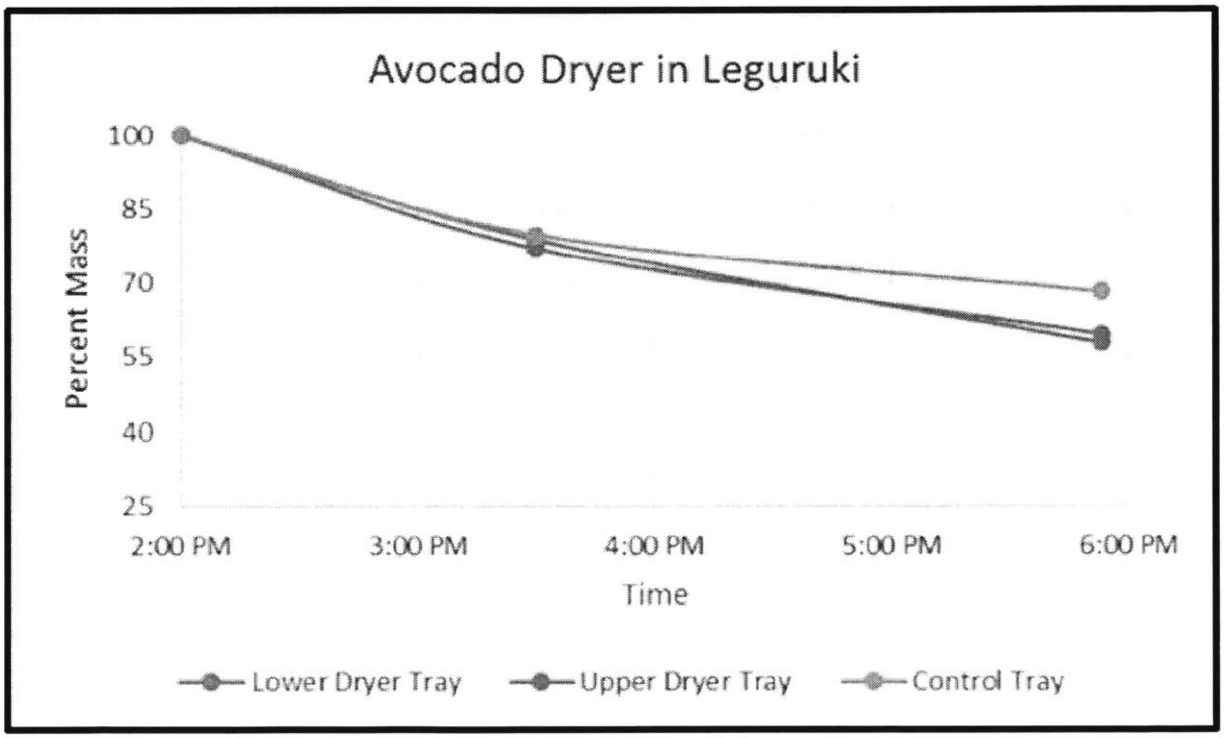


Figure 9: Results from the Solar Dryer 2.0 in Leguruki on a sunny summer day in January. Because the weather was so hot, you can see that the dryer did not make a significant difference until afternoon, when the sun began to cool but the dryer retained heat. In order to collect data, the clear tarp was opened and closed multiple times, creating error in data [9].

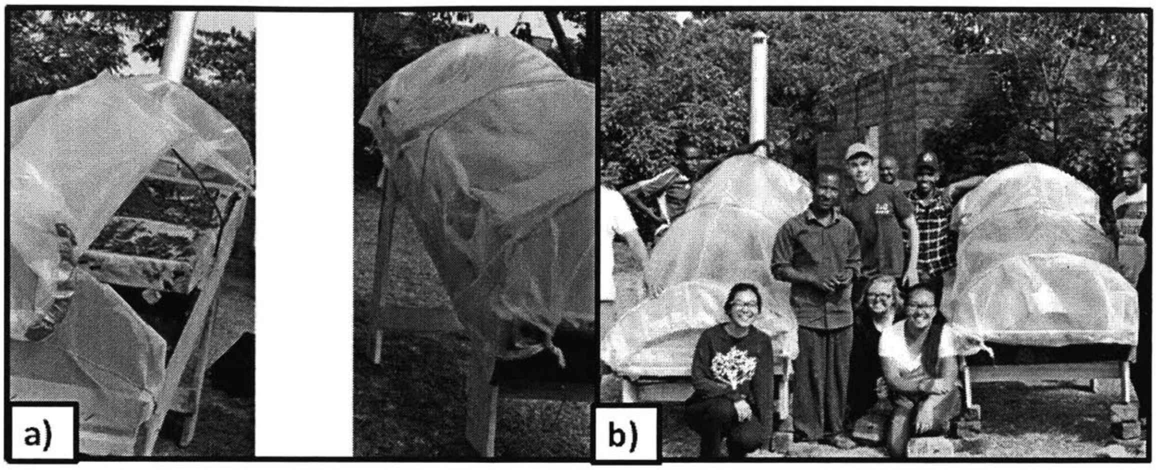


Figure 10: Solar Dryer 2.0 Dryers built in Leguruki. One tunnel dryer had an additional chimney for added ventilation.

3.4.3 Solar Dryer 2.0 (Leguruki): Learnings

Solar Dryer 2.0 was a solid improvement from Solar Dryer 1.0, both in creating airflow and offering protection during the entire drying process. But, when analyzing this dryer in regards to cost and quantity per batch, it no longer seems the practical route. If it were possible to cut the cost of constructing a similar dryer, this design could be reconsidered. Future additions of an electric fan to increase airflow and moisture reducing mesh openings are possible avenues for future development. However, this prototype was constructed with input from local community partners and using local materials. The most significant learning from this experience would be learning how to communicate with and building relationships with our local community partners.

After construction of this prototype, market research led to the discovery of criteria of cosmetic grade oil produced under 50°C. Solar collectors do not fulfill this criterion, so, further pursuit of dryer designs was halted.

3.5 Hand Drill Centrifuge (Arusha)

Since learning more about the quality of oil required for cosmetic grade oil, both the MIT team and locals temporarily explored alternative methods of oil extraction. Looking at industrial methods of cold pressed avocado oil extraction, it seemed that most producers use centrifugation.

3.5.1 Hand Drill Centrifuge (Arusha): Design

At the end of the MIT team's visit in Arusha in January 2015, a preliminary prototype was built for centrifugation. A plastic bottle filled with small amounts of mashed avocado was connected to a high-speed hand drill by the lid.

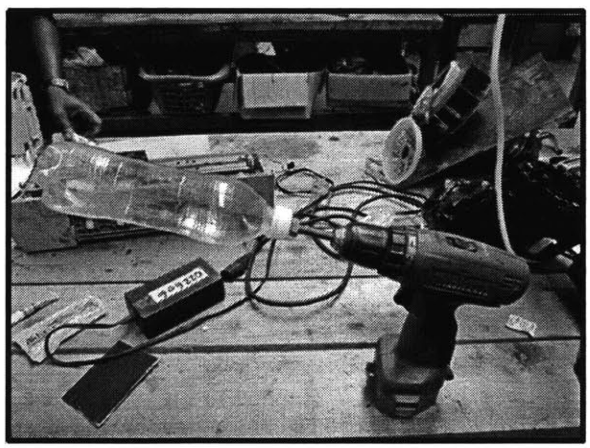


Figure 11: First prototype of an avocado centrifuge constructed with a plastic bottle and a hand drill. The bottle was very prone to spinning off the drill, and the small radius of the bottle and speed of the hand drill was not nearly enough to extract oil.

3.5.2 Hand Drill Centrifuge (Arusha): Results

The hand drill centrifuge prototype was used by putting mashed avocados into the bottle so that it was around a third full, pointing the hand drill downward, and running the drill until for 30 second intervals. Although exact measurements of the test no longer exist, an approximation acceleration of the centrifuge can still be can be estimated. If the water bottle is around 4cm in radius and a standard hand drill can go to speeds of up to around 1500 rpm, the avocado in the bottle would be experiencing around 100G of acceleration.

From these experiments, no visible oil was extracted, leading Avomeru to conclude that the centrifuge needs to exert more force. Longer trials were not possible to execute as the junction from bottle cap to hand drill was not strong enough to withhold trials for much longer than 30 seconds; the bottle was not securely fastened to the drill and flew off the drill.

3.5.3 Hand Drill Centrifuge (Arusha): Learnings

As this was the first attempt at centrifugation, the team discovered that centrifugation is not a simple task; it is not easy to get to high accelerations at a small scale. However, the failure of this prototype did not discourage the teams from continuing to pursue centrifugation as a method for oil extraction.

3.6 Horizontal Centrifuge 1.0 (MIT)

The first centrifuge prototype was designed with the goal of safely operating while meeting a baseline acceleration of 330 G for 2 minutes, baseline conditions that were able to extract oil from avocado mash in laboratory experiments, described in Section 3.6.3.1 [10]. With a 1hp motor that will reach 2500 rpm, it was determined that our centrifuge drum would need to be around 10 cm in diameter in order to reach 330G, the minimum oil extraction force.

3.6.1 Horizontal Centrifuge 1.0 (MIT): Design

The design consisted of a cylindrical drum attached to a steel axle sitting between two bearings. The two bearings were bolted down to a wooden platform. The axle held a pulley connected to another pulley that a motor of 1hp turned. With three sizes of pulleys to choose from, we could test a range of speeds. In order to allow for the oil to separate from the mash more easily, the avocado mash was contained in very fine nylon mesh bags held in place with metal mesh inside the drum, curling around the axle. In addition to the centrifuge, a safety case was built for centrifuge which consisted of sheet metal bent and riveted to fully cover the centrifuge in case any shards fell off while the centrifuge was running.

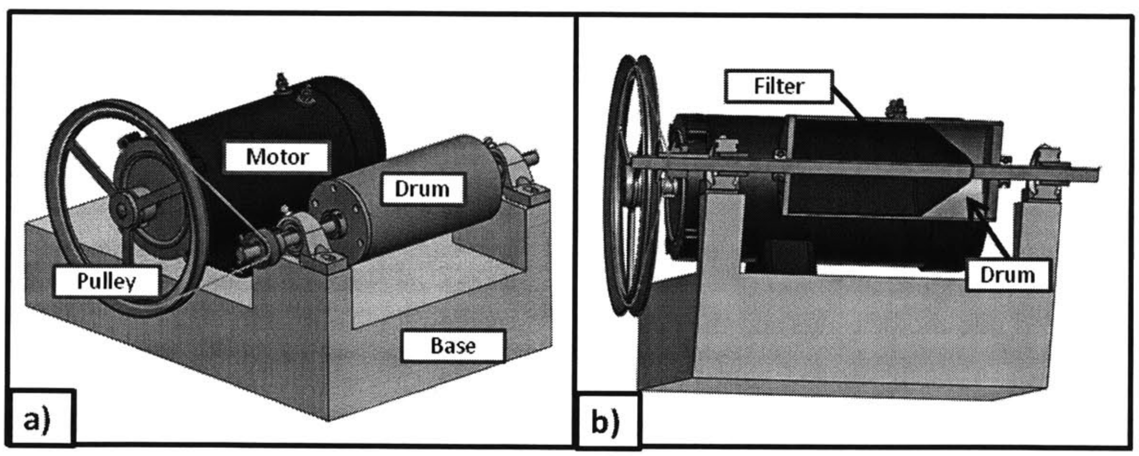


Figure 12: 3D model of Centrifuge 1.0 a) 3D model of Centrifuge 1.0. Consists of a 1 hp motor, steel drum, and pulley system, on a base. b) The inside of the drum contained a fine nylon mesh filter held in place using steel mesh.

While most parts were off the shelf orders, the metal drum was constructed by welding steel sheet metal to two thin steel plates, water jet to fit the axle. Only one end of the drum could be removed by unscrewing six hex screws around the perimeter of the drum.

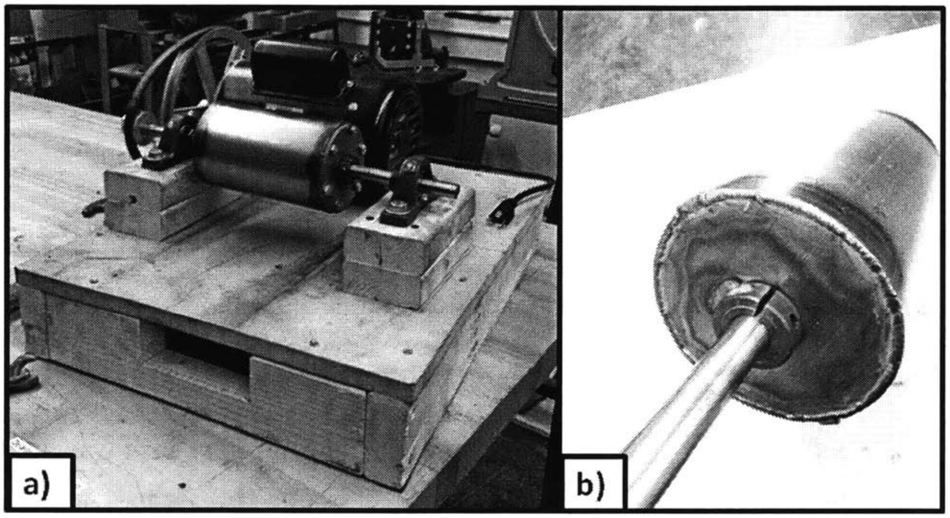


Figure 14: Centrifuge 1.0 a) Centrifuge 1.0; very similar to 3D model in Figure 13. b) The drum of the centrifuge was horizontal and made of steel sheet welded to round steel ends. This attachment was non-uniform and created much imbalance to the centrifuge, magnifying noise and vibration.

The first test was run by loading avocado mash into a mesh bag. Once loaded into place, the drum was loaded into the bearings and the centrifuge turned on for 2 minutes.

3.6.2 Horizontal Centrifuge 1.0 (MIT): Results

After centrifugation, small amounts of the avocado had been pushed through the mesh such that the entire nylon cloth and steel mesh layer was removed from the drum. When the avocado was taken out of the container, too much was stuck in the drum and could not be extracted easily, ripping the nylon cloth. In addition, there was not enough oil separated to filter out. Because of this, measurements of the mass of avocado mash to oil were not made. However, from observation, there seemed to be an extremely thin layer of oil outside of the nylon cloth. When the contents of the drum were emptied into a bowl, oil drops gradually floated to the top. The figures below show the visible oil drops, not present before, as a result of the centrifugation (Figure 15, Figure 16). However, it was not enough oil to test decanting and filtering methods. Although there were not conclusive results, the prototype did reach the necessary speed to extract oil and several lessons were learned to be implemented on the next prototype.

Figure 15: Comparing Pre/Post Centrifuge Avocado Mash Avocado mash before and after centrifuging. There are large oil drops present on the surface of the avocado mash that has been centrifuged, in comparison to the smaller oil drops on the sample.

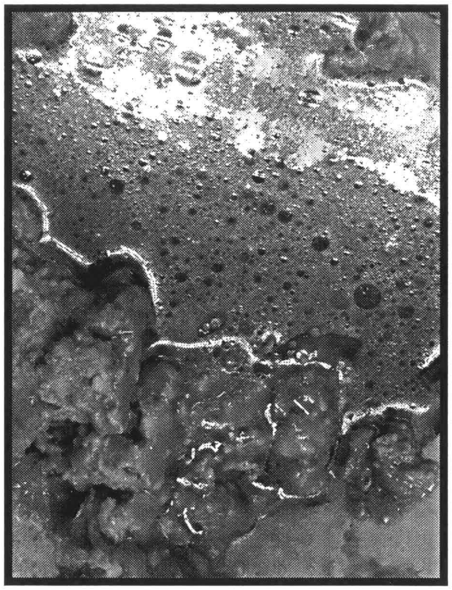


Figure 15: Post Centrifuge Avocado Mash Close up picture of avocado mash after centrifugation. Very apparent separation between the solid mash, water, and oil. Oil is a thin layer on top.

3.6.3 Horizontal Centrifuge 1.0 (MIT): Learnings

This section is separated into two sections: Section 3.6.3.1 focuses on laboratory centrifuge testing performed to set a baseline for Horizontal Centrifuge 1.0, while Section 3.6.3.2 is refers to the learnings from making and testing the prototype Horizontal Centrifuge 1.0.

3.6.3.1 Centrifugation Learnings: Laboratory Testing

While working on the first centrifuge design, Voca performed baseline experimentation to understand avocado oil extraction at varied centrifuge accelerations, hoping to find a minimum acceleration necessary for oil extraction, in order to set a baseline goal for our avocado prototypes. Because of design variations and control, Voca prepared the avocado samples in a similar fashion but used a laboratory centrifuge to alter the speed ensuring accuracy and precision in measurement.

Avocado was first prepared by being sliced in half, removed of the seed, spooned out and mashed in a bowl. Avocado is then compressed and malaxed for 40 minutes with additional water added. Afterwards, samples of avocado were centrifuged at 330, 480, 760, and 1350 G's. It was found that as acceleration was increased, yield increased but even at the lowest acceleration speed tested, 330G, that oil extraction efficiency is still over 6%. An experimental report by members of team Voca shows an in depth description of the experimental setup, methods, and results used during this experimentation [10].

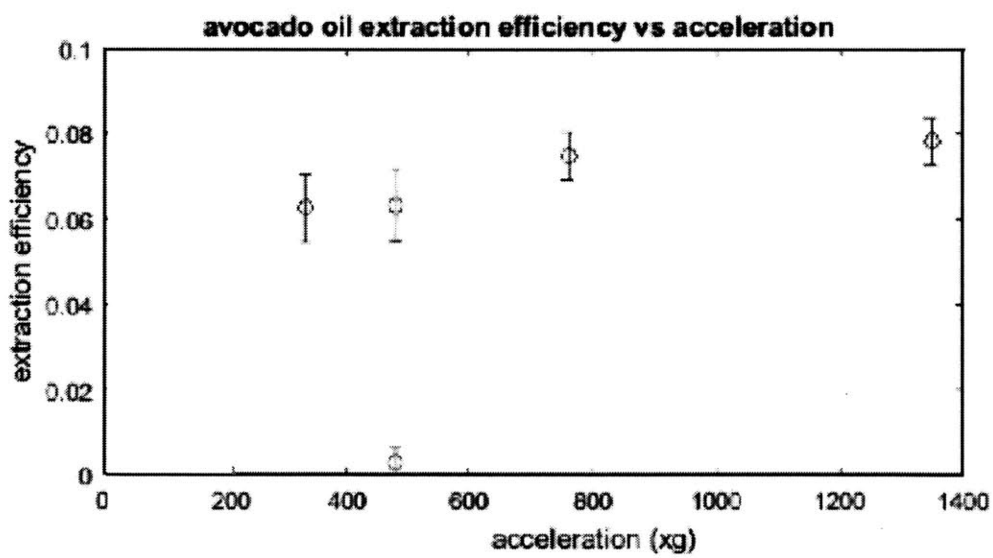


Figure 17: Baseline Avocado Oil Extraction Efficiency vs. Acceleration Plot of avocado oil efficiency at different centrifuge accelerations. One can see that even at 330 G, the oil extraction efficiency is not significantly different from higher accelerations. For more detailed description of experimental setup and data analysis, refer to the experimental report by team Voca [10]. Note: the apparent

outlier should be discounted; the sample used change in mass instead of total mass for that particular calculation.

A process briefly mentioned in the previous experimentation was malaxing. Malaxing refers to continuous slow mixing in the presence of low heat, a process that was found to great increase the oil yield. Malaxing allows for small droplets of oil to combine into larger, more visible droplets and made a visible difference in samples tested by Voca. Because the limit for cold-pressed avocado oil is 50°C, Voca malaxed the avocado mash with added water for around 40 minutes, similar to the process industrial machines use, while keeping the avocado temperature around 45°C, just under the temperature limit. While in a lab setting, Voca controlled the avocado mash using a thermometer and a hot plate, all while mixing by hand. Although malaxing was only tested with centrifugation, it could potentially change the oil yield when pressing for oil.

3.6.3.2 Centrifugation Learnings: Prototype Testing

Several lessons were learned with the first prototype, which were taken into consideration later on. First, because the drum was constructed in the shop as opposed to purchased from an industrial manufacturer, it was not perfectly balanced. Although weights were added to opposite sides, the drum and hand-welded joints were not perfectly even. Because avocado mash was being used, it was hypothesized that as the drum spins, uneven amounts of avocado mash would eventually spread itself along the wall of the drum, allowing for a balance in weight. However, we were unsure whether this was the case as the drum was opaque. Because of the imbalance in the drum, especially when full, the centrifuge was subject to much noise and vibration. Although the centrifuge could run for two minutes, VOCA did not feel comfortable letting the machine run for longer due to excessive vibration.

The drum of the centrifuge was constructed mainly of steel sheet metal. When not cleaned properly and the avocado is not contained, a good deal of rust began to form. In addition, the caps of the drum were only able to be removed via six hex screws with little room for error. Because of the axle in the center of the drum, it was also difficult to position the mesh bag of avocado mash in an even manner without ripping the bag on the mesh.

3.7 Horizontal Centrifuge 2.0 (MIT)

Taking the insights acquired through the first prototype, a second centrifuge was designed now that we understood the speed the motor could reach. This time, the focus was on creating a symmetrical, even rig for the drum and to ensure that the design of the drum allowed for easy access and maintenance.

3.7.1 Horizontal Centrifuge 2.0 (MIT): Design

In order to keep the centrifuge more balanced, a clear, industrial, polycarbonate cylinder was purchased to act as the drum and two end pieces were cut on a ShopBot CNC machine. Each end piece had a groove cut into the wood that the polycarbonate drum could fit into and a hose clamp was fit onto the wood and tightened to keep the end caps in place. Other than the clasps to the hose clamps, the entire drum was perfectly symmetrical and balanced properly, assuming the polycarbonate and wood could be approximated with constant density. Similar to before, an axle ran through the middle of the drum, held in place with two adjustable collars and loaded on two bearings. The bearings were then attached to adjustable blocks that were held in place with a moveable lock on a rectangular 80-20 chassis, ensuring that, although the bearings would be able to move to allow for the pulley wheels to be changed more easily, they would always remain parallel to each other. An 80-20 rectangular chassis was chosen in order to keep angles straight and lengths perfectly symmetrical, to reduce possibilities of uneven placement. In addition, the axle was extended to be twice as long as the drum so that the lid of the drum could be easily removed and pulled apart without being fully detached from the axle (Figure 15). To address the problem of rust and cleaning, polycarbonate was used as it does not rust and all avocado mash and filters were put inside a waterproof bag to contain all possible leaking. In order to reduce noise and vibration, the assembly was placed on several layers of insulating pink foam (not shown).

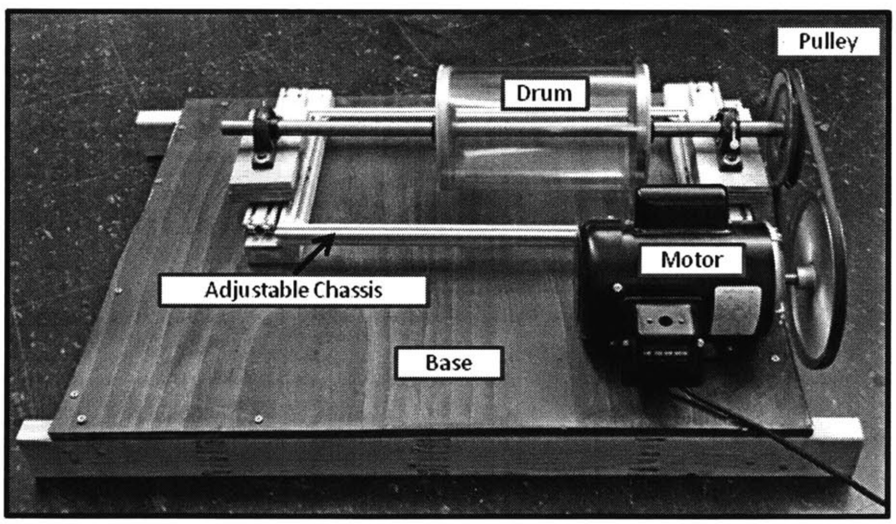


Figure 18: Centrifuge 2.0 Centrifuge 2.0, iteration on the previous model. The design remained very similar but the entire drum was attached to a moveable chassis that allowed for easy access to the contents of the drum. Unfortunately, the chassis was too unstable to be tested with a load of avocado.

3.7.2 Horizontal Centrifuge 2.0 (MIT): Results

This centrifuge was unfortunately never tested with avocado. The joints were not as stable, as the centrifuge was designed to be easily alterable. The centrifuge could be comfortably run for about a minute, with no avocado added, but fasteners, specifically the locks securing the bearings in place, would begin to loosen for longer runs. Because the centrifuge could not successfully run for more than a minute empty, the centrifuge was not tested with avocado mash as the avocado would only further decrease stability. The amount of noise and vibration was not significantly reduced by the new design, although ease of access, setup, and upkeep were drastically improved. Therefore, no measurable oil extraction experiments were run on prototype 2.

3.7.3 Horizontal Centrifuge 2.0 (MIT): Learnings

Due to time constraints and the lack of potential for the design, further reinforcements could have been added to the joints, but were not pursued. However, this design taught that the inherent design of these two prototypes is very prone to noise and vibration at high speeds and it is incredibly difficult to build, especially with the skills and tools readily available in D-Lab.

3.8 Vertical Centrifuge (Leguruki)

Met with the challenge of cold-pressed oil, Avomeru also briefly explored centrifuging with a vertical centrifuge.

3.8.1 Vertical Centrifuge (Leguruki): Design

The vertical centrifuge consisted of two steel bowls whose lips were welded together one on top of the other, to form a vertical drum, and attached to a frame made of steel extrusions. A motor was attached to the bottom portion of the axle using a pulley. As the avocado mash spun in the drum, the drum would act similarly to a traditional lab centrifuge and the avocado would be separated into layers surrounding the axle.

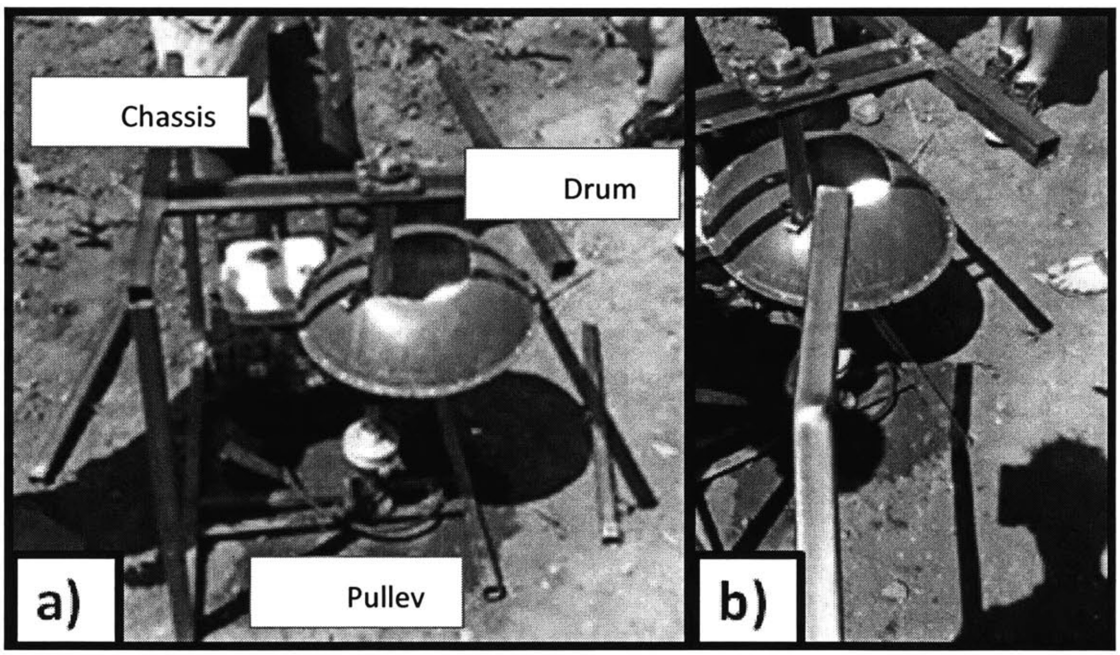


Figure 19: Vertical Centrifuge When Voca and Avomeru met in Tanzania summer of 2015, they worked together to create a vertical centrifuge design. Unfortunately, the centrifuge was not stable enough to run and broke almost immediately on testing.

3.8.2 Vertical Centrifuge (Leguruki): Results

This design was extremely weak and, as shown in the figure above, led to failures in the structure. The centrifuge did not last for more than 1 minute and resulted in very dangerous metal shards being flung out. The steel extrusion frame was broken, and the bowl was torn. Problems resulted mainly from the lack of structural integrity which was exacerbated by the excessive noise and vibration due to imbalance.

3.8 .3 Vertical Centrifuge (Leguruki): Learnings

As the first real attempt Avomeru made to centrifuge, the failure of the vertical centrifuge was a big learning experience. The lessons of stability, structure, and balance were highlighted as well as the importance of safety in all designs. This experience also discouraged Avomeru from continuing to pursue centrifugation as a method of oil extraction.

3.9 Spin Dryer Centrifuge (MIT)

Researching centrifugation and potentially adaptable machines, the idea of adapting a table top spin dryer to become a centrifuge was discussed. Prototype 3 focused on testing whether it is plausible to be able to alter a table top spin dryer into a centrifuge able to reach forces necessary for avocado oil extraction.

3.9.1 Spin Dryer Centrifuge (MIT): Design

The main incentive for pursuing this idea was the built-in dampening system in tabletop spin dryer. Because VOCA continually struggled with noise and vibration, taking advantage of the washer's dampening system and already balanced drum would automatically significantly reduce such problems. The design of this centrifuge consists of taking a tabletop spin dryer and adding a hollow cone to the inside of the drum as shown in the figure below (Figure 20). During centrifugation, the different phases are avocado are separated according to density, with the less dense substances (oil) on the inside and more dense substances on the outside (water, solids). The design takes advantage of this separation in order to force the inside layer of oil up the slope of the cone and into the opening at the very top of the cone. After centrifugation, the oil is collected inside the cone, allowing for easy removal and skipping the step of filtration.

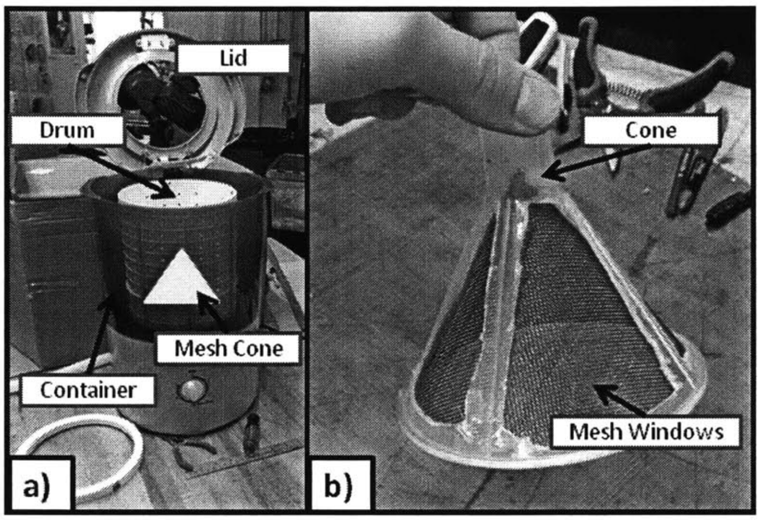


Figure 20: Spin Dryer Centrifuge This prototype consists of an altered countertop spin dryer. A mesh cone (figure b) has been attached to the middle of the centrifuge such that when the avocado is spun and is split into layers of oil, water, and solid, the liquids will be at the center and will pass through the mesh, entering a compartment at the bottom of the centrifuge.

The spin dryer used was the Mini Portable Countertop Spin Dryer by The Laundry Alternative rated for 1750 RPM. With a radius of over 10 inches, the modified spin dryer centrifuge should be able to achieve extraction force on the order of 300G.

3.9.2 Spin Dryer Centrifuge (MIT): Results

The team is in the process of testing this technology and fully evaluating the centrifuge.

3.10 Press with Additives (Leguruki, Dar Es Salaam)

While exploring the market of avocado oil in Tanzania, the MIT D-Lab development team found one man who was producing 700 L of avocado oil every harvest in Tanzania. He lives the Dar Es Salaam and serves as a Director of Crop Development at the Ministry of Agriculture. After visiting him and speaking with him, it was found that his method of oil extraction was not centrifugation but mixing in rice stalks with the mashed avocado in a 1:1 ratio and pressing the mixture through a mesh. He then decanted the oil twice and extracted the pure oil to sell. We learned that he owns a large avocado farm with purely Hass and Fuertes avocados, the strain with highest oil content. He sells the oil mainly for cosmetic or health uses by word of mouth from close family and friends. Buyers would directly pour the oil onto their skin or hair. His business is growing as he sells out every season and is looking to expand.

After unsuccessful attempts with the centrifuge and hearing about NZalawahe's methods of pressing the avocado with cornstalks, the local team began trying NZalawahe's methods for themselves. Avomeru has changed the ratio to 7:3, rice stalk to avocado, and are currently using machines originally for seed oil extraction that have been altered.

4. Results and Discussion

The technology used in this project can be divided into three types: solar dryers, centrifuges, and presses. After examining and working with these machines, attributes and criteria of function can be determined for each type of machinery, as well as for avocado oil extraction on the whole.

4.1 Solar Dryers

Examining the methods for removing water content from avocado mash, the set of common criteria across all models were found to be the following:

DRYER CRITERIA	PERFORMANCE REQUIREMENTS
Protect against weather, animals, insects	Provide coverage at all points of drying process.
Drying Time	<12 hrs, to reduce oxidation Faster than air drying
User Friendliness	Does not require constant supervision Can learn to use in <1 hr <30 minutes to load & clean
Quantity Throughput	>1 square meter of mash/load
Cost	<$150

Table 1: Avocado dryer criteria and baseline measurements. The criteria shaded are critical to function while the other criteria are still critical but largely determined by the user or market.

The solar dryer *must decrease the drying time* of avocado in sunny and overcast weather. To decrease the dry time of avocado, the dryer can either increase the temperature of the avocado or increase the amount of airflow above the mash, or both. The total amount of time the avocado mash is left out to the air should be less than 12 hrs, in order to reduce the amount of oxidation and spoilage the avocado experiences which affects the smell and taste of the oil. When drying avocado mash spread on mesh on the ground, it was found that animals and insects are attracted to and would disturb the drying process. In order for a dryer to be productive, it needs to *provide basic protection* against animals, insects, the weather, and other possible pollutants. These three criteria are critical to the success of a solar dryer.

Other criteria certainly affect the success of a dryer design but depend on the user's requirements. While the first three criteria are essential to the function of the dryer, the following criteria are important but do not render the dryer ineffective. *User friendliness* is a very important criterion which contains several different facets; user friendliness can be defined by how much supervision the dryer requires, how often it needs to be checked on, how intuitive it is to learn to use and how much skill is required to use the machine. The last of the criteria is *cost*—the baseline would be defined by the user and the market. Speaking to locals interested in the oil pressing design, it seems that around $150.00 would be a ceiling for a community dryer.

When designing and building solar dryers, an effective process of evaluation for the success of the dryer is described in Table 2 below. At each stage, the designer should only move on if the answer is affirmative to each question.

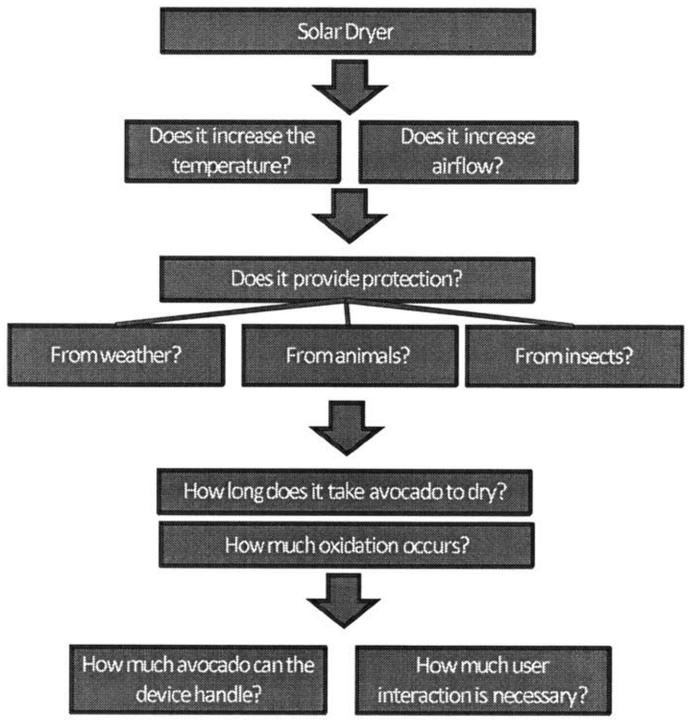


Table 2: Flow chart on thought process when evaluating a solar avocado dryer.

Keeping these criteria in mind, the models of dryers built in the oil extraction process as described earlier can be compared.

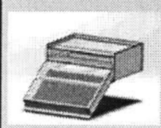
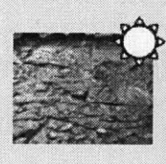
		Oil Quantity	Dry Speed	Quality	Protection	Cost
	Solar Collector	N/A	N/A	N/A	Provides adequate protection from all animals, insects and elements	Fairly low cost; however, aluminum cans are not common in TZ
	Slanted Tunnel Dryer	1L/12hr	In sunny weather: slightly faster than air drying In overcast weather: much faster than air drying	Non-cosmetic grade oil; *minimal* pollutants	Provides adequate protection from all animals, insects and elements	High cost, around $100
	Drying in Sun	No limitation on batch size	In sunny weather: one batch/12hrs In overcast weather: unsuccesful; moldy avocado	Non-cosmetic grade oil; *many* pollutants	No protection; subject to animals and insects	Little/no cost

Table 3: Comparison of avocado drying methods tested throughout this process. Because many of the measurements were qualitative evaluations, descriptions are provided as opposed to quantitative critera.

4.2 Oil Extractors (Presses and Centrifuges)

Examining the methods for final oil extraction, centrifuging and pressing, it was found that the criteria for the two methods were very similar. The set of common criteria across all models were found to be the following:

OIL EXTRACTOR CRITERIA	PERFORMANCE REQUIREMENTS
Enough force to extract oil?	2000psi/330G
Safe/Structurally sound?	Structurally able to withstand 2000psi/330G Safely run for 50,000 cycles/5 mins Minimal noise and vibration
Rate of Oil Extraction?	1L/hr *determined by user/market
User Friendliness	Does not require constant supervision Can be learned to use in <1 hr <30 minutes to load & clean
Cost	$400

Table 4: Common avocado press centrifuge criteria and baseline measurements. Note that the criteria highlighted in red are critical to function while the other criteria are still critical but largely determined by the user or market. Criteria can be slightly different for press versus centrifuge but general criteria are largely the same.

The centrifuge or press must, first and foremost, *exert enough force or acceleration to extract oil* from the avocado mash. This baseline, from previous experimentation, was set at 2000psi/330G. In addition, the equipment must be *safe and stable*, both in terms of structure, but also balance and vibration. In particular, if using a centrifuge, it should maintain structural integrity and should not produce any projectiles. The *rate of oil extraction* can be affected by the load size, that is, how much avocado the machine can process at one time, the press time per load. The maximum *cost* allowable is determined by the amount of money the farmers or Avomeru would be willing to spend on such a machine. Depending on the business model, location, and available capital, the baseline for cost could vary greatly. When speaking to local farmers, they seemed to be willing to spend up to $400.00 on a machine such as a centrifuge that could extract avocado oil for the entire community to use.

When designing and building avocado centrifuges or presses, an effective process of evaluation for the success of the dryer is described in Table 5 below. At each stage, the designer should only move on if the answer is satisfactory to each question.

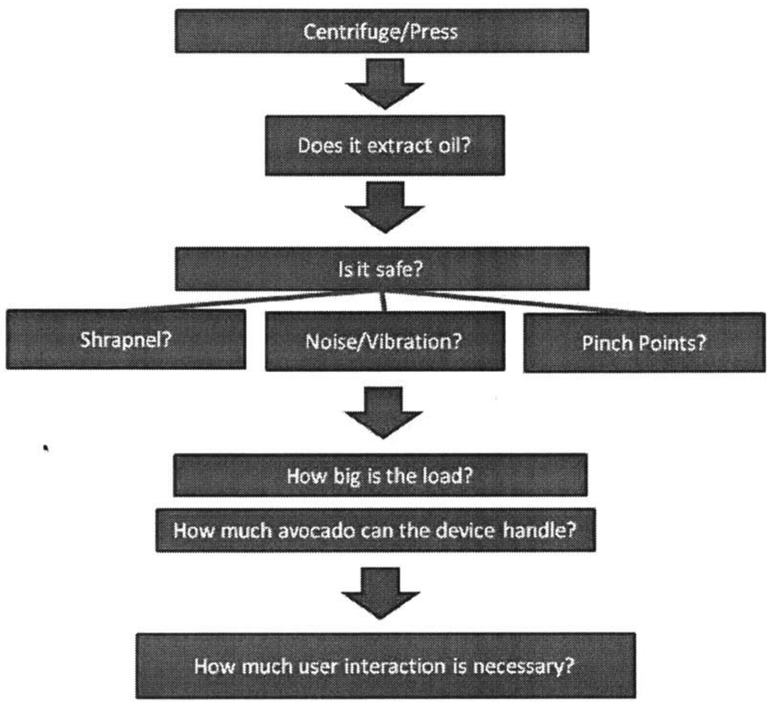


Table 5: Flow chart on thought process when evaluating an avocado press or centrifuge. Certain questions pertain to one machine more than the other but general process is very similar.

The set of criteria can be used to compare the models of presses used during process previously described.

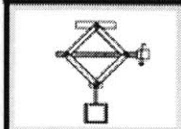
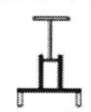
		Quantity of Oil	Speed	Safety	User Friendly	Cost
	Jack Press	Slightly less than jack press	Rate > 1L/hour (including prep time)	Very safe	Easy to use; fairly easy to clean	$25
	Standing Press	Less than jack press	Faster than jack press	Less safe than jack press	Less friendly than jack press	<<$25
	Hammer Press	Much less oil extracted than jack press	Faster than jack press	Much less safe than jack press	Much less friendly than jack press	<<$25
	Screw Press	0.5L/batch	Rate > 1L/hour (including prep time)	Very safe	Easy to use; fairly easy to clean	<$50

Table 6: Comparison of avocado pressing methods tested throughout this process.

The set of criteria can be used to compare the models of centrifuges used during process described in section 2. The criteria used are very similar than that of the presses but slightly altered in order to better compare centrifuge designs.

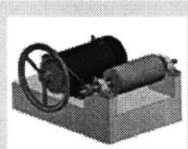
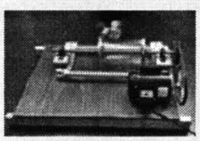
		Oil Quantity	Safety	User Friendly	Cost
	Hand Drill	0L/hr	Flew off hand drill; low risk due to low speeds	Extremely user friendly; all avocado contained within	Extremely inexpensive
	Vertical	0L/hr	Shrapnel, structurally unsound, extremely dangerous	Difficult to clean but easy to access avocado	N/A
	Horizontal Drum 1.0	0.01L/hr	Maintained structural integrity but large amounts of noise and vibration	Difficult to clean and access avocado	~$400
	Horizontal Drum 2.0	N/A*	Large amounts of noise and vibration led to structural	Designed so that all avocado stays within one bag; easy to clean and access	Slightly more expensive than Horizontal Drum 1.0 due to 80-20 rig
	Spin Dryer	N/A*	Structurally safe, minimal noise and vibration Note: tested w/o avocado	Easy to operate but difficult to clean	~$200

Table 7: Comparison of avocado centrifugation methods tested throughout this process. Note *: Spin Dryer Centrifuge and Horizontal Drum 2.0 were not tested due to centrifuge instabilities with avocado in order to determine the amount of oil extracted.

As the process to avocado oil extraction has been mainly focused on empirical testing, full tests with were not collected for all prototypes, leading to incomplete data to evaluate the technology. For this reason, more testing should be performed to fully understand the parameters of avocado oil extraction and the degree of success each prototype achieved.

Solar Dryer Prototype 1.0, the model built and tested at MIT, should be tested with malaxed avocado mash and compared to a control sample out under the sun and tests with other solar dryers. Because the temperature was measured without avocado for this prototype, there is not an accurate measure as to how evaporation would change the temperature. In addition, with all solar dryer prototypes, not only should water loss and temperature gradient be measured, but also airflow, to understand the relationship between rate of evaporation to change in temperature and airflow. From previous studies, it was learned that airflow has a greater affect on evaporation than temperature, but there has yet to be testing find the correlation between airflow and evaporation in the solar dryer prototypes.

For the centrifuge prototypes tested in this process, much testing was done on an extremely basic level, essentially determined by whether the centrifuge could withstand use or not. Many of the prototypes were not successful in extracting oil, and therefore dismissed very early on. However, in order to be able to test the degree of success each centrifuge achieved, more testing should be performed on each centrifuge. Each centrifuge should be tested with full loads of malaxed avocado mash for various times to test the oil yield for different lengths of time. These results should then be compared to lab centrifuge yield results. This comparison will also be able to determine how scalable centrifugation is as an oil extraction method as lab centrifugation occurs at a much smaller scale than the prototypes built and tested. Further research on oil yield from industrial machines would be helpful in determining the target efficiency for oil extraction centrifuges.

5. Conclusion

Through this analysis, a set of criteria was created in order to evaluate future technologies involved in the oil production process. In the pursuit of cosmetic grade avocado oil, Avomeru and Voca, teams from Tanzania and MIT, respectively, have iterated through several designs and experimented with various machinery. By analyzing the design choices and results of several solar dryers, presses, and centrifuges, it is apparent that avocado oil extraction on a small scale is a complicated task. However, some learning can be extracted, although there is a need for further work. Oil quantity, safety, user friendliness, and cost should always be kept in mind when designing for avocado oil extraction.

Aiding Avomeru in the process of oil extraction and developing a business is Voca's main focus. As an oil-producing method has been found, future research and design should be performed on refining the current oil production method, pressing with additives, and focus on other limiting factors in the process. Speaking with Avomeru, they are currently exploring pasteurization and filtration. Further research on the pasteurization process and perhaps pasteurizing before beginning the pressing process using high pressure pasteurization (so that the oil remains cold-pressed) would be beneficial to the quality of oil. In addition, the preparation step where avocados are peeled, pitted, and mashed, is currently very tedious and limiting, and there is technological potential to design a machine to fulfill that gap. Although efficiency is typically a concern when considering any machine, oil extraction efficiency is not as critical in this context; avocados exist in abundance so the cost of inefficiency is not as high.

Through developing this suite of technologies, Avomeru is now a business, working with 28 cooperatives of farmers in Leguruki, supplementing their normal incomes. This technology, with further improvements, could be disseminated to other countries with similar avocado excesses or room to grow avocados, affecting the lives of small-scale farmers around the world.

6. References

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