

Exploration of avocado oil extraction methods and potential in rural Tanzania

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Introduction

Throughout the fall 2014 semester, we, a team of six MIT students and two trip leaders, explored the potential for extracting oil from avocados via drying and pressing methods in Leguruki, a rural Tanzanian village. We then traveled to Tanzania for the first three weeks of January 2015. In Tanzania, we participated in the co-creation of several dryer prototypes, researched different directions for oil extraction, performed preliminary market research, and connected our community partners with new contacts. This work was carried out as a final project for D-Lab:Development. This report focuses on our process of designing an appropriate dryer for the conditions in Leguruki, the key findings from our market research, and our recommendations for the project's future. Though we focused most of our time throughout the semester on producing a solar dryer, after our experience in the field, we are no longer certain that this is the best route for oil production, and we strongly encourage further consideration of the other options that we discuss in this report.

Background

In July 2014, an IDDS (International Development Design Summit) was held in Tanzania.^[1] Representatives from various regions, who showed promise and an interest in design, were invited to participate in the month-long event. IDDS members made field visits to 4 different communities, Leguruki being one of them. Several members of the Leguruki Community were further involved in the summit, participating on either the “coffee team” or the “avocado team.” The avocado team identified avocado excess as a potential area for innovation. From speaking with community members in Leguruki, our team has confirmed that almost every person who lives in the village is a farmer and has some number of avocado trees. People,

however, do not consider themselves avocado farmers; they just happen to have avocados. Harvesting and selling avocados produces such a low return for most due to the commonality and short shelf life of avocados that most people allow the bulk of their avocados to just fall to the ground and be eaten by livestock or rot. The IDDS team designed a press in hopes of extracting additional value from the avocados by making oil, but they did not realize that, due to the high water content of avocados removing the water either before or after the pressing is essential for the production of quality oil. Several of the IDDS coordinators attempted to build a make-shift tunnel dryer, but it was not effective and resulted in a mass of rotting avocado. This is where the dryer project began for our D-Lab team.

People in Leguruki have had success with laying tarps on their roofs and spreading avocados on them to dry via direct sunlight on particularly sunny days. By speaking with avocado growers in Leguruki, we determined that the peak avocado harvesting seasons are July through September and January through March, which correspond to humid and overcast weather conditions, making traditional drying methods less effective.

Within Leguruki, there are two prevailing business models that we have seen around the potential production of oil. One idea is to produce oil on a commercially-viable scale for profit. This may entail selling the oil to a cosmetics company for soaps, shampoos, moisturizers, etc... The other idea, which is perhaps more applicable on the local level, is to produce avocado oil for use as cooking oil on the individual scale, replacing sunflower and olive oil. We spoke with several people in Leguruki about how much they currently pay for cooking oil and were told that sunflower oil typically costs between 3,500 and 5,000 TSH/Liter. Both the large and small-scale plans have the potential to achieve the goal of income-generation, but the feasibility of each plan depends on a great deal of factors, including the quality, consistency, and volume of oil that can

be produced as well as the size of the local, national, and global avocado oil markets. We give our initial analysis of these factors in the market research section of this report.

It is also important to note that power in Leguruiki is fairly limited. As far as we are aware, all power is collected via solar panels. We were told that Leguruiki is scheduled to gain access to the power grid within the next couple of months, but it was mentioned that similar claims have been made in the past. This power constraint is something we considered seriously in our design plans.

Pre-IAP Work

Our team began the semester by exploring several different dryer designs. Initially, the team split into three groups and did independent research on fruit drying in developing countries. Each team considered environmental conditions, material constraints, and community needs in Leguruiki. These considerations culminated in the following problem, need, and potential solution sets (Table 1). Our initial dryer models were created to align with these solutions.

Table 1. Initial evaluation of problems and needs associated with avocado drying as well as proposed solutions

Problem	Corresponding Need	Solution
Wild dogs eating avocados while they are laying out to dry	Avocados must not be easily accessible	Dryer should be an enclosed system
Avocados rot while drying	Dryer must dry within about 6 hours	Increased ventilation and temperature
Lack of Electricity	Dryer should use either solar or wind-power	Use some kind of solar collector
Low availability of capital for target users	Dryer needs to be inexpensive	Inexpensive, easily-sourceable materials and manufacturing

Avocados all ripen at the same time	Large volumes of avocado need to be dried simultaneously	Drying solution for large volumes needed
Importation of materials is expensive	Use local materials	Wooden dryer

After collaborating in our three smaller groups, we presented ideas to the entire team. Two groups converged on one dryer design (Figure 1), while one group created the second design (Figure 2).

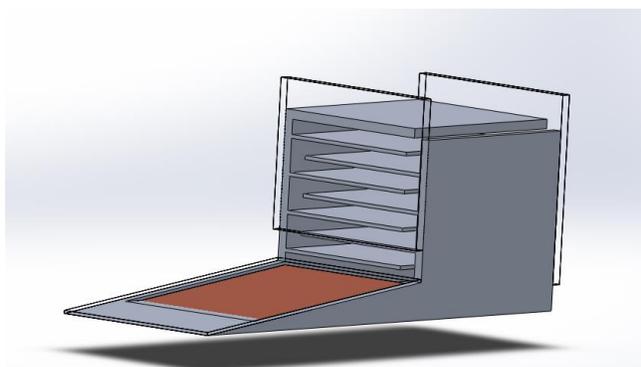


Figure 1. Dryer design 1

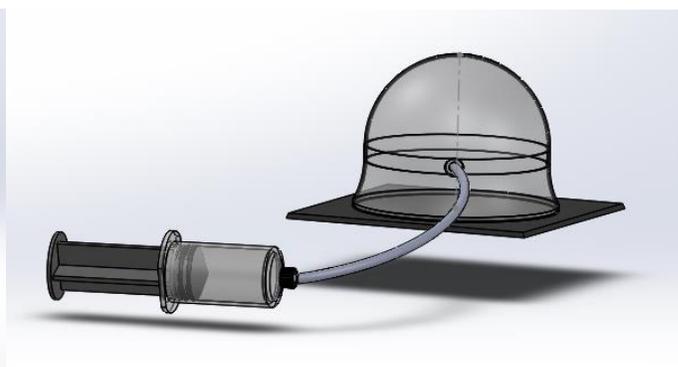


Figure 2. Dryer design 2

Dryer 1 includes a solar collector and several racks on which avocado could be placed. The team theorized that air would pass over the metal plate, become warm, and then move through the dryer and over the avocados, drying them before passing out of the back of the dryer. The aim of dryer 2 is to pump air out of a sealed space, reducing the pressure, and therefore reducing the heat requirement for water evaporation, causing the avocados to be able to dry at a lower temperature. Dryer 2 had a limited capacity and issues with availability of materials but, theoretically, satisfied the need for a closed system and fast drying rate. Dryer 1 seemed, overall, like a very practical design, aligning with almost all of the proposed solutions presented in Table 1. After a failed proof-of-concept experiment on Dryer 2, the team chose Dryer 1 design.

Refining Design through Experimentation

Once we converged on a single design, our team performed a series of experiments to better understand the avocado drying process. These experiments addressed the following variables: avocado geometry ventilation, drying temperature, and desirable solar collector properties.

Experiment 1:

Setup: In our first experiment, we wanted to decide whether mashed avocados or sliced avocados dried faster. We removed the skin and seed from Hass avocado and put 116g of mashed avocado on one plate and 103g of sliced avocado on another. Both plates were massed prior to the application of avocados. Mashing was done with a mortar and pestle until there were no visible chunks of avocado remaining. Slices were between 3mm and 7mm thick. We tried to control the amount of plate area that was covered by avocado in each case so that the average thickness of mashed and sliced avocado would be similar on each plate.

Procedure: First, we placed the plate with sliced avocado in the microwave for two minutes. After two minutes, we removed the plate and recorded the mass. We did this 13 times for a total of 26 minutes in the microwave. We then repeated the same procedure for the mashed avocado plate. The plates were removed from the microwave for no more than 30 seconds for each massing.

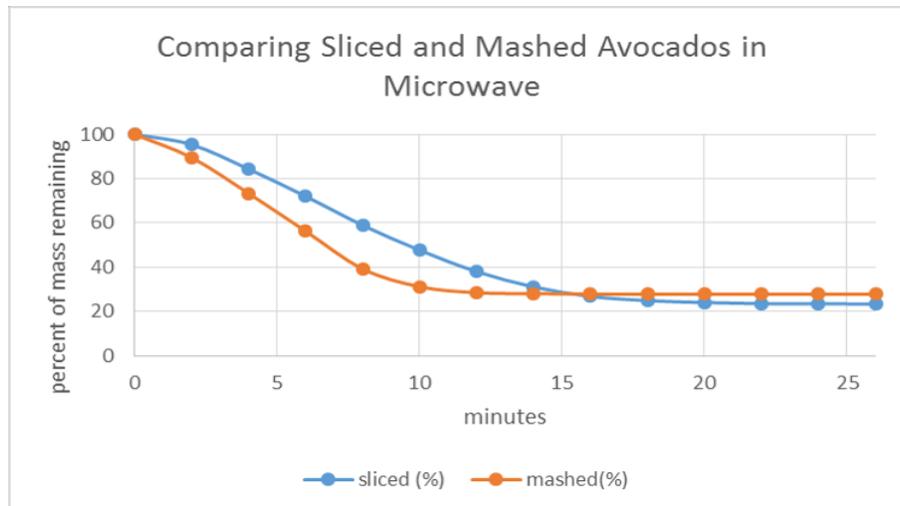


Figure 3. To properly compare the two avocado geometries we plotted percent of avocado mass remaining versus total time in the microwave. We then compared the maximum rate of drying for mashed and sliced avocados.

Between the 6th and 8th minutes, both plates experienced the greatest loss of percent grams. This loss was 8.5 percent for the mashed avocado and 6.6 percent for the sliced avocado. We did not account for the difference in initial mass between the two trays because there was such a great difference in maximum percent lost between mashed and sliced avocados that we felt confident concluding, without completely controlling initial mass, that, in a microwave, mashed avocados dry faster than sliced avocados.

Experiment 2

Setup: Our second experiment focused on dryer type while confirming the difference between drying rates of mashed and sliced avocados. We carried out the same procedure involved in experiment 1, but we used a small oven instead of a microwave because the humidity dynamics within an oven are more similar to those of a solar dryer. We prepared the mashed and sliced avocados in the same way as in experiment 1, but we used small tins instead of plates. Each tin was filled with 10g of avocado. We prepared three tins of mashed avocados and three tins of sliced avocados.

Procedure: We allowed the oven to heat up to a constant temperature and did not supply any external ventilation. We placed all six tins into the oven on the same rack. We then recorded the remaining avocado mass for each of the six tins every half hour for the first several data points and then every hour as the mass loss began to decrease. We recorded the oven's temperature each time we recorded the samples' mass. The oven fluctuated between 59.5 and 68 degrees C over 18 hours for an average of 64 degrees C.

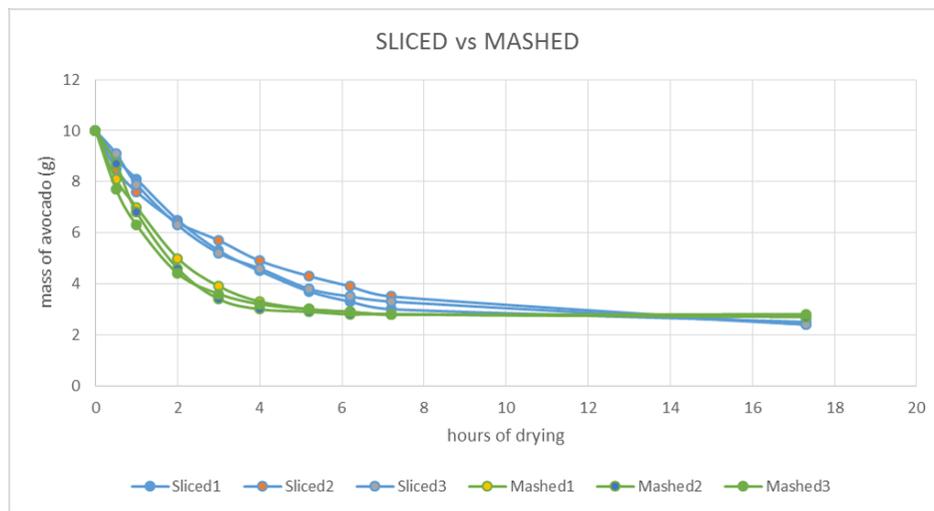


Figure 4. Mass of avocado remaining plotted against total time

On average, dryer efficiency (maximum rate of mass loss in grams/hour for a given trial) for the three mashed avocado tins was 4.1 g/hour. Average dryer efficiency for the sliced avocado tins was 2.5 g/hour. Mashed avocados again dried considerably faster than sliced avocados.

This data is a good fit to an exponentially decaying curve (See Table 2), suggesting that drying rate is directly related to the percent water remaining in the avocado. We use this mathematical model for the remainder of our avocado drying analysis. We also realize that

exponential decay implies that the maximum loss of water mass occurs as the samples are placed in the dryer, which is consistent with our data, as five of our six tins in this experiment had a maximum drying rate at the first data point. The sixth tin had a maximum at the second data point. Therefore, five tins had determined dryer efficiencies after the first half hour and the sixth after an hour, which can be extrapolated to mean that if, under time constraints, we can only measure weight after the first half hour or hour, we can still get accurate information about dryer efficiency.

Table 2. R-squared values for data fit to an exponentially decaying curve

Sample	r² value
Sliced1	0.9980
Sliced2	0.9926
Sliced3	0.9984
Mashed1	0.9988
Mashed2	0.991
Mashed3	0.9997

Experiment 3

Setup: In our third experiment, we sought to understand how the thickness of mashed avocado affects dryer efficiency. We prepared 9 tins with 10g of mashed avocado each. For three of the tins we spread avocado across the entire bottom of the tin. For another three tins, we spread avocado over only $\frac{3}{4}$ of the base area. On the last three tins, we spread avocado over only $\frac{1}{2}$ of the base area. Since each tin had the same mass of avocado, the tin with the least base coverage corresponds to the thickest avocado sample.

Procedure: Each of the 9 tins was placed on the same level in the oven. Two small fans that consumed 14V together were placed on the same rack as the tins in the oven's opening. Air

entered through this opening and exited through the top of the oven. Dryer temperature was 55 degrees C over the half hour testing period.

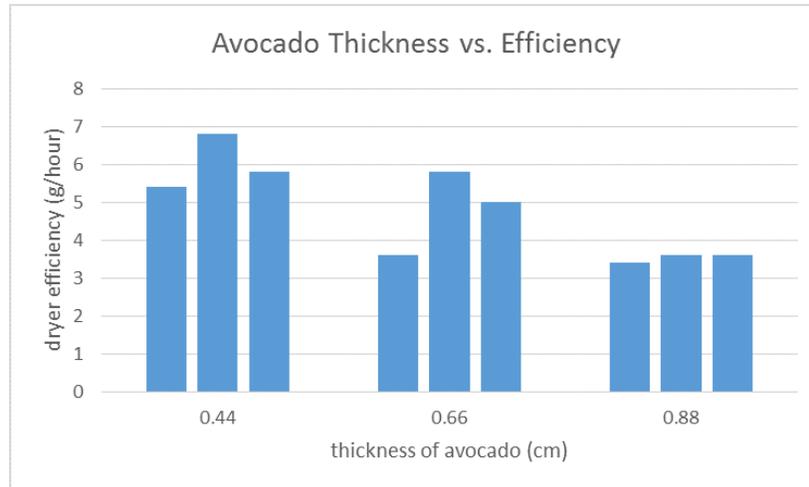


Figure 5. Dryer efficiency (max rate of mass loss in grams/hour for a given trial) plotted against thickness of avocado

Given the mass, density, and coverage area of avocado, we could calculate the average thickness of the thin, medium, and thick avocado samples. The results show that, to maximize dryer efficiency, the avocado mash should be as thin as possible, implying that surface area is directly related to dryer efficiency. In future experiments, we decided to spread avocado as thinly possible due to this observation. Limitations such as fixed tray sizes and difficulty in spreading evenly made a thickness of 0.44cm our practical lower bound. We incorporated a large tray area into our first dryer prototype to accommodate this optimal thickness.

Experiment 4

Setup: Experiment 4 was designed so that we could analyze the effect of ventilation on the drying process by drying avocado samples in the oven with and without fans running. For the data without the fan, we used the mashed avocado data from experiment 2. For the experiment

with the fans, we used the same setup as in experiment 2, but we added 2 small fans, which consumed 14V together.

Procedure: The mass of each tin was recorded every hour. The trial without a fan had an average temperature of 64 degrees C. The trial with a fan had an average temperature of 57 degrees C.

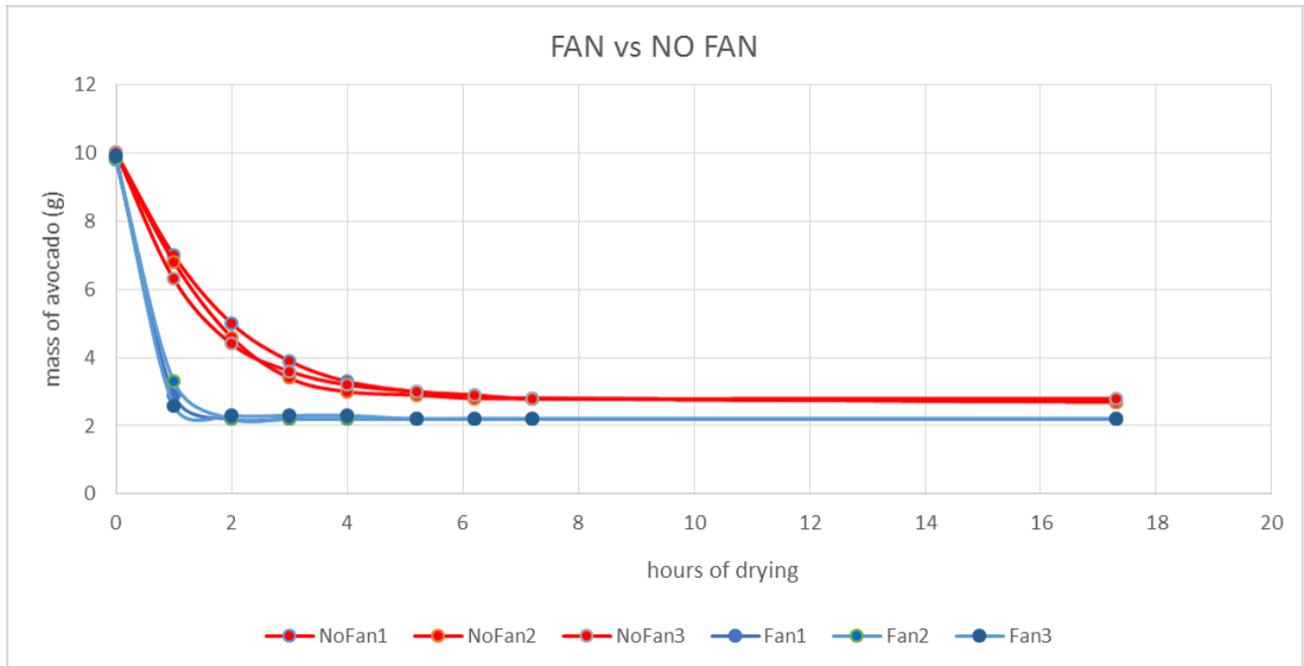


Figure 6. Exploration of dryer efficiency with a fan and without a fan

The two small fans made a large difference in dryer efficiency. This experiment helped us realize the supreme importance of ventilation. The fact that the trial without a fan had a higher temperature by about 7 degrees C means that ventilation has a greater impact on dryer efficiency than temperature.

With this experiment in mind, in our first dryer prototype, we placed our solar collector at an angle to optimize air flow from the solar collector to the tray area. Maximizing the temperature difference from top to bottom of the solar collector is a high priority, as a temperature differential encourages buoyancy-driven ventilation.

Experiment 5

Setup: In experiment 5, we aimed to understand how temperature of the oven affects avocado drying efficiency. We performed three trials with low, medium, and high temperatures. Fans were turned on, 10g of mashed avocado were spread onto each tin, and tins were placed on the bottom level of the oven for each trial.

Procedure: For the medium temperature trial, we used the data from Experiment 4, which included three tins of avocado. For the other two trials, we tested six tins of avocado per trial. For each trial, three tins had unripe avocado and three tins had ripe avocado. We did not find a noticeable difference between the unripe and ripe avocado drying rates, thus we can assume that all six tins are comparable. The temperatures were 46, 57, and 74 degrees C. Two trials were performed for the low and high temperature tests.

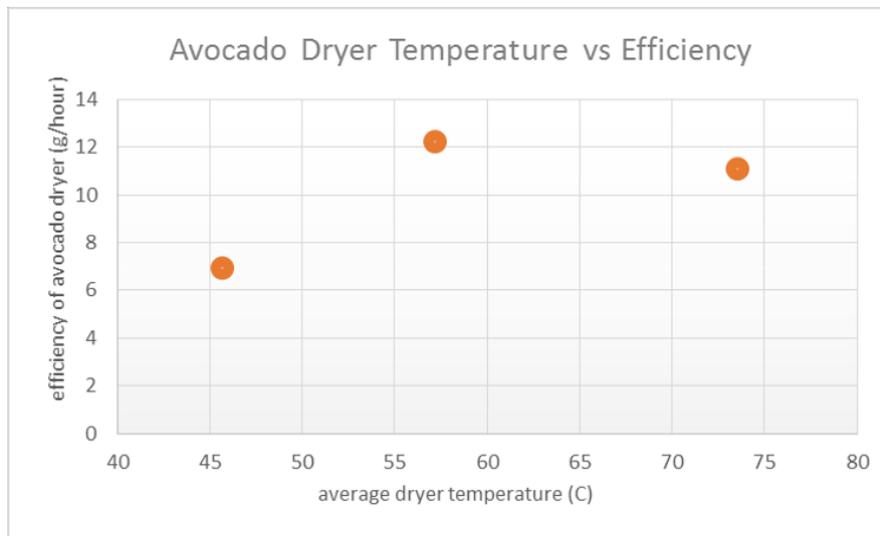


Figure 7. Average drying efficiency relative to temperature

We concluded that around 57 degrees C is ideal for drying avocado quickly. In Tanzania, we learned about temperature and how it effects oil quality. We now think that temperatures

above 50 degrees C should be avoided, which we discuss more in future work, but we did not know this information when we were designing our first prototype, so it could not yet inform our design choices.

Experiment 6

Setup: In this experiment we aimed to understand which type of solar collector heated air best in a closed region. This experiment tested different solar collector coverings and heating elements. We made six cardboard boxes with varying coverings and heating elements at the bases. Each box was 8 inches tall and had a base of 12x12 inches. The base of each box was covered with wood, steel sheet, and aluminum cans. These heating elements were all painted black and glued into place. Wood acted as our control, as we expected it to heat up the least. Coverings were securely taped to the top of each box in an attempt to make the boxes air-tight. Coverings included thin plastic sheet, thick plastic sheet, and plastic bottles (See Figure 9). For the plastic bottles, we cut off the top and bottom of each plastic bottle and then cut them in half length-wise (See Figure 8). These halves were stapled together to form a tight seal the covered the box opening. We chose these solar collector elements and coverings based on their perceived availability in Leguruki, Tanzania. The six boxes were created as follows: wood with a thick plastic covering, wood with a plastic bottle covering, steel with a thin plastic covering, steel with thick plastic, aluminum cans with thin plastic, and aluminum cans with thick plastic. We punctured a small hole in the center of one side of each box so that we could make temperature measurements as the boxes were exposed to heat.



Figure 9. Box configurations



Figure 8. Plastic bottle covering

Procedure: Overcast and cold weather conditions forced us to test the boxes with heat lamps rather than with direct sunlight. Boxes were placed under two heat lamps of 75W and 40W. Both heating lamps were within 8 inches of the top of the box. Once the box was placed under the heat lamps, temperature was recorded every 30 seconds. This procedure was repeated for each of the six boxes.

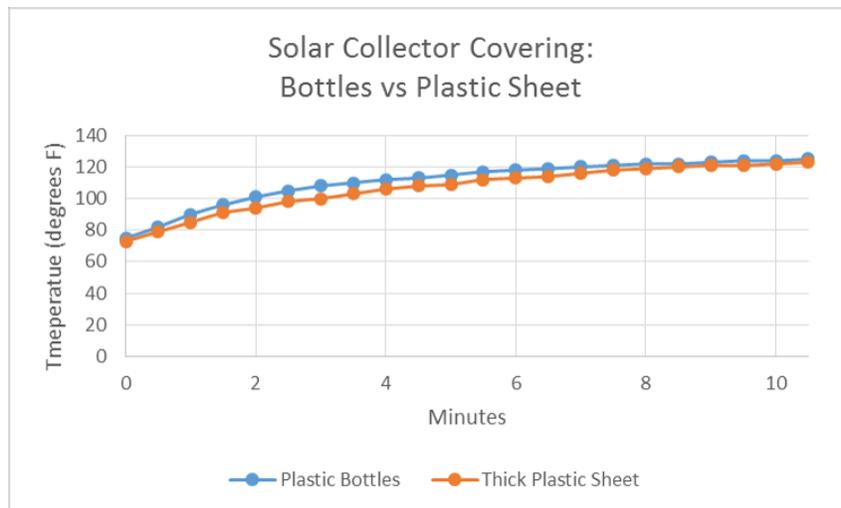


Figure 10. Comparing temperature of solar collector with wooden heating element covered with either thick plastic sheet or plastic bottles

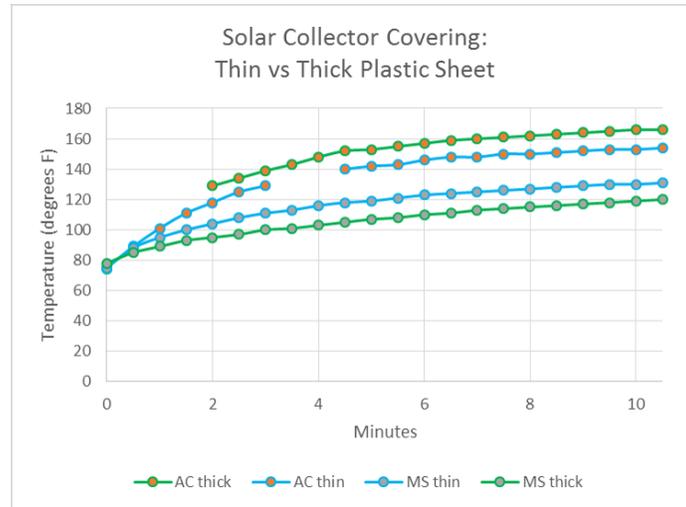


Figure 11. Comparing effectiveness of aluminum cans (AC) and a steel metal sheet (MS) as heating elements while comparing thin and thick clear plastic sheet

The gaps in the data were due to collection errors where we either missed data points or the temperature given by the thermal couple was unreasonable. Different coverings seemed to make little difference in overall temperature of the box. A plastic sheet performed almost exactly the same as the water bottles, as seen in Figure 10. When aluminum cans were used as the heating element, thick plastic was better, and for steel metal sheets, thin plastic was better (Figure 11). We are unsure of the reason for the different performance between the thin and thick plastic based on the heating element. We think the observed differences may be due to leaks within the boxes that allowed different amounts of hot air to escape.

Solar collector elements, however, made a large difference. Aluminum cans heated up much faster than steel sheets. We do not know if this is mostly due to differences in geometry between cans and a sheet or due to the difference between aluminum and steel. The metal sheet was much heavier than the aluminum cans, so thickness of metal could also be a factor to

consider. From this experiment, we concluded that a solar collector of aluminum cans with any clear, plastic covering would produce more heat than bare, black-painted wood or steel sheet.

Final Dryer Design and Testing

Based on all previous experimentation, we believed the ideal dryer should reach 57 degrees C, have ample ventilation, have a large tray area so that avocado can be exposed to moving air, and have a solar collector of aluminum cans with some sort of plastic cover. These conclusions informed the decisions we made in building our first dryer prototype (See Figure 12). The design is fairly simple, including a solar collector attached to a cabinet area that houses two trays. These two trays compromise between ventilation and surface area. The design was created to promote air flow across the avocado instead of around it. The two trays of 4x3 feet allow enough surface area for about 10kg of mashed avocado to be dried. We thought the angle of the solar collector would allow for a temperature differential that was great enough to provide ventilation.

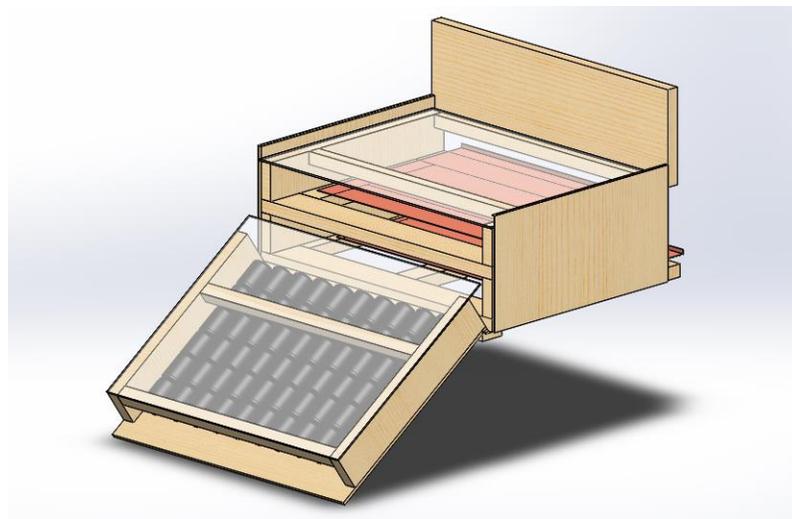


Figure 12. First dryer prototype

After conceptualizing this design, the team began building the dryer in order to test it and to gain hands-on experience in dryer-building as preparation for our field work in Leguruki. We spent approximately 60 man hours constructing this dryer. We estimate that a skilled wood worker could construct this dryer in 2 days and that the material for this dryer cost no more than \$250.



Figure 13. Photo of completed prototype in D-Lab workshop

We then performed a short test on the dryer to see how well it responded to heat and light. We placed 4 heat lamps over the solar collector and recorded temperature of air before it entered the solar collector and after it exited the solar collector (Figure 14).

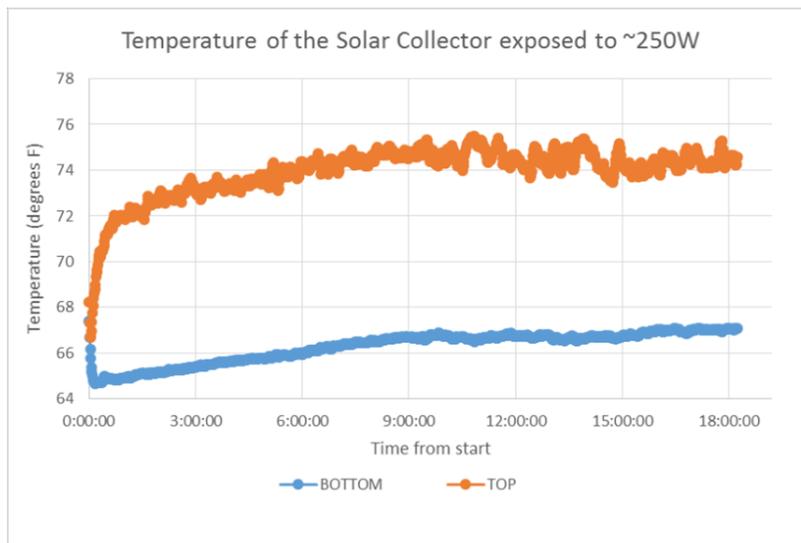


Figure 14. Temperature differential between top and bottom of the solar collector

The average increase in temperature from the bottom of the solar collector to the top was 7.76 degrees F. We believe this differential succeeded in creating air flow, as we could feel air escaping from an opening at the joint of the dryer. We expect that the temperature differential would increase significantly when actually set outside on a sunny day.

Project Goals

Before leaving for Tanzania, our team identified several broad goals. We wanted to build a solar dryer, as we believed this would be the most efficient solution for drying avocados. We also wanted to put a lot of emphasis on engaging the community in the co-creation process by designing, testing, and building with the community rather than for the community. Tying into an initiative by IDIN, we also wanted to increase our understanding of local innovation.

After completing the dryer construction phase of our trip, we identified several more goals. We wanted to get a solid understanding of how avocado oil is extracted on an industrial scale, whether avocado oil could serve as a cooking substitute for sunflower oil at the scale of the Leguruki village, and determine whether there is a market for locally-produced avocado oil in Tanzania. We also thought it was necessary to collect feedback on our dryer designs and provide a final recommendation based on this feedback and our own observations.

Community Partners

Community Partners are community members who have taken an interest in this project and its future development. Many of these partners played a role in IDDS as well.



Penuel has shown the most interest in the continuation of the project after the completion of IDDS. He received a picogrant and furthered the press that was developed during IDDS (Figure 15), and he independently developed designs for an avocado oven (Figure 16) that used charcoal as a heat source.

We have been in close contact with Penuel, and he clearly intends to produce his own iterations of the dryers we made in Leguruki. He is a farmer and barber who became involved with the avocado project after he saw the work done during IDDS. He has been drying avocado on his roof when weather conditions allow and then pressing the cake for oil. He sees avocado oil production as a potential business.



Figure 15. Penuel demonstrating the function of his press

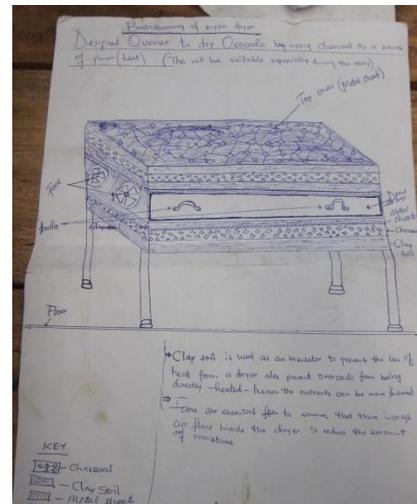


Figure 16. Penuel's initial avocado dryer design

Pastor Emmanuel is interested in producing high quality oil as a way to increase income for his



congregation. He is a talented woodworker and was integral in building our dryers in Leguruki. Prior to our arrival, he experimented with avocado drying at differing stages of growth and ripeness (Figure 17). He lives about 20 minutes from central Leguruki and leads a congregation that includes many avocado growers. He is very excited about this project

and willing to explore different methods of producing avocado oil, such as cold pressing and centrifuging.



Elliot works for Global Cycle Solutions in Arusha and juggles multiple projects, the furthering of this avocado oil production project being one of them. He was an IDDS organizer and has a good relationship with and a lot of knowledge concerning the many stakeholders in Lguruki and their attitudes and motivations. He is a 2014 course 2 MIT graduate and a D-Lab alum.



Jesse was a member of the IDDS coffee team and has served as a vital asset in many ways. He has many talents and wears many hats (translator, driver, innovator, friend) and accompanied us nearly 24/7 during our stay in Arusha and Leguruki. He is originally from Leguruki, and his family is well-respected by the community. He is intelligent, innovative, and, overall, very helpful. We strongly recommend that he be involved with all related future work.



ECHO is a sustainable farming NGO in Arusha (about 2 hours from Leguruki) that was tasked with IDDS project follow-up, receiving a grant from IDIN to carry out this function. Local project follow-up would involve supplying materials, technical support, and ideas to the individuals in Leguruki who are interested in the continuation of the project. ECHO is headed by Erwin. During our stay in Tanzania, we spent time with ECHO and shared initial design ideas and results from our prototypes. Several ECHO members came to Leguruki on one of our dryer-building-days to help assemble the dryers.



Jonah, Jesse's cousin, lives in Moshi but was invited by Jesse to join us during our prototyping. He is interested in the project's potential. He has taken the lead on market research and has been investigating the standards for differing oil usages. He joined us while the dryer was being built and has been heavily involved since. He is Jesse's cousin and has been collaborating with Penuel frequently since our arrival.



Bernard is an electrician by trade but loves innovating machines. He participated in IDDS and now works for AISE and has a lab space that can be used to build prototypes for new designs. He helped us with new centrifuge prototypes.

Leguruki Dryer Construction

From speaking with several of our partners in Tanzania, Erwin and Elliot specifically, we created three modified design ideas. One idea involved modifying an old, discarded fridge. We

planned to lay the fridge on its side and add a solar collector, similar to our MIT dryer design. We had been told by some of our partners that broken refrigerators are relatively available in Arusha, though we did not see any ourselves. We found the main fault in this design to be the limited and inflexible volume. With a more scalable model in mind, we again considered building a second version of our MIT prototype, as the main box portion of the dryer has flexible dimensions that could be altered to meet demand. An issue with this design is the large quantity of raw material required, which is important to consider in Leguruki, as wood is quite expensive. (We paid 9,000 TSh/6 foot board). We settled on a third design (Figure 18), which is essentially a modified tunnel dryer.

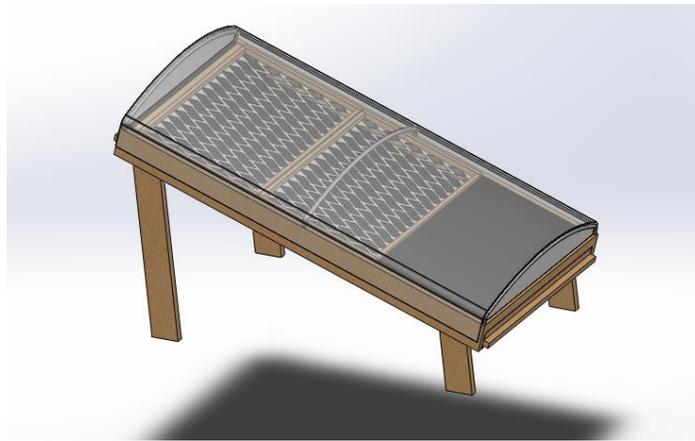


Figure 18. Tunnel Dryer

The simplicity of the design construction as well as the scalability of the design influenced us to choose this dryer to build and test. The features we considered to be integral to the design include the clear plastic sheet that covers the dryer, the angle of the tunnel, and the sheet of aluminum at the entrance. We painted the aluminum sheet black to maximize heat absorption. It begins at the entrance of the dryer and covers one third of the length of the dryer. The clear plastic should create a green house effect, trapping in the heat from the sun, raising the

internal temperature of the dryer above ambient temperature. We planned for the angle between the base of the dryer and the ground to be about 30%. Hoping to promote air flow through the dryer, we expected air to enter the dryer and then heat up as it moved through the tunnel due to the green house effect created by the plastic sheet. The angle of the tunnel facilitates ventilation upwards and out of the dryer, as hot air rises.

The wooden body is approximately 2 meters by 1 meter, which we decided on with the thought that it would be small enough to be transported via car. Three metal rods were bent into arches and inserted into the wooden frame to produce the skeleton for the clear, plastic tarp cover. On the two side edges of the plastic sheet, we folded the plastic over on itself and sewed a seam, creating a small passage through the plastic along the edges of the dryer. Wire (about 2mm diameter) was fed through this passage on both sides of the dryer, and, on one side, the cover was nailed directly into the wooden frame. On the other side, holes were poked through the plastic sheet above where the wire was fed through the plastic. Nails were then nailed halfway into the other side of the dryer to correspond with the holes in the plastic. To close the dryer, the holes in the plastic were looped around the nails. By allowing the dryer to be opened from one of the sides, the trays could be placed and removed via the sides rather than through the front or back, which proved to be difficult. The trays, wooden frames with a fine, strong mesh serving as the base, fit exactly into the body of the dryer and used a set of rails on both sides of the wooden frames to support themselves. Each tray took up 1/3 of the 2 meter dryer length. The same mesh used in the trays was also used to cover the entrance and exit of the dryer. The mesh allows air to move through the dryer but stops insects or pests from entering the dryer. In order to stop air from escaping through the bottom of the dryer and to encourage the air to move directly through the tunnel, the underside of the dryer was covered with a black plastic tarp.



Figure 19. The left image shows how the plastic sheet can be peeled back to assist in tray placement. The right image shows how the dryer can be sealed.

We also made a second, slightly-modified version of this design (See Figure 21), which incorporates a chimney made from aluminum sheet metal. We thought the chimney would help create a pressure differential, which would allow the dryer to sustain greater ventilation.

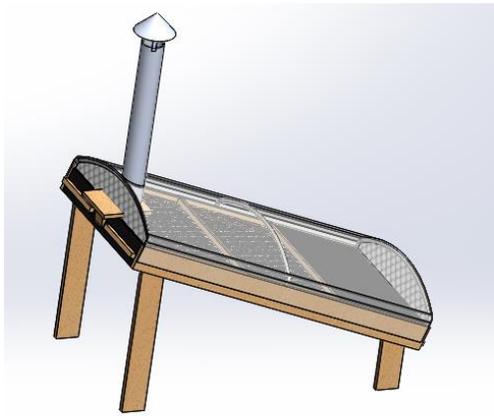


Figure 21. Modified tunnel dryer with chimney



Figure 20. Team with completed dryer prototypes

Dryer Experimentation

We were able to conduct several experiments in conjunction with our community partners in Leguruiki. After completing the first tunnel dryer (Figure 18), we filled the two corresponding trays with avocado and set them in the dryer. We laid a third tray on the ground next to our dryer to compare the drying power of our dryer to the drying power of undisturbed,

direct sunlight. We peeled the avocados, removed the pits, and then mashed the remaining flesh to produce a relatively consistent avocado mash for these experiments.

Four and a half kg of mashed avocado were spread on Tray 1, which was then placed in the lower portion of the dryer, while four and a half kg were applied to Tray 2, which was then placed in the upper portion of the dryer. We did not have enough avocado mash to entirely fill Tray 3, but we compensated by only spreading the avocado on about 1/3 of the entire tray surface, giving each tray about the same average avocado thickness (0.75 cm). The experiment began at 2:00pm on 1/15 and masses were collected periodically.

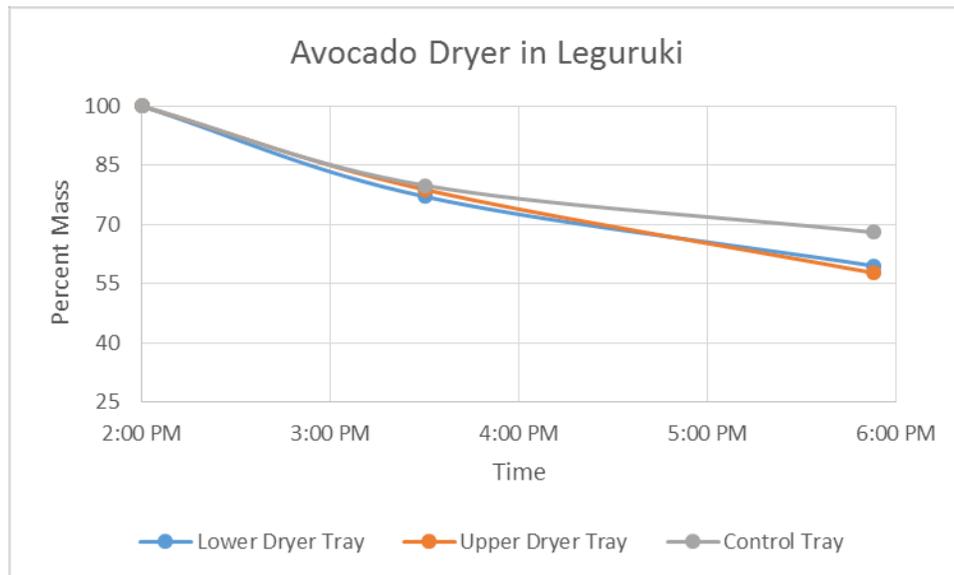


Figure 22. Results from first Leguruki dryer experiment

The avocado in all three of the trays underwent a phenomenon called “case-hardening.” Relating to this work specifically, case-hardening occurs when the surface of the avocado mash that is in contact with the air dries much more quickly than the layers below. We are unsure if case-hardening can be overcome by just allowing more time to dry, but it is possible for the

avocado to dry completely if it is continually mixed every several hours, allowing new avocado to be exposed to the surface.

We also note that avocado was able to drip through the mesh. This means that some avocado that was initially weighed fell from the tray and affected the overall mass of the tray. We believe it is still possible to compare overall percentage loss of the trays, as percentage loss of avocado through the mesh should be approximately equal across all three of the trays. Therefore, our dryer performed about the same as the control tray, but as the sun went down, our dryer continued to dry as the control cooled off and stopped drying as quickly. Average temperature of the control avocado was 31 degrees C where average temperature of the avocado in the upper tray of the dryer was 38 degrees C.

After this experiment, we decided that the mesh trays needed to have some type of covering, and we did some experimentation to determine which type of covering would be the most useful. We set up experiments for both the lower and upper tray position in the dryer with the chimney. On the upper tray, half of the tray was covered with the same aluminum sheet that was used previously in the dryer construction, and the other half of the tray was covered with a black, plastic sheet. On the lower tray, half of the tray was covered with the clear, plastic sheet, which was used to cover the dryer, and the other half was covered with the black plastic (See Figure 23). We also made a modification to the way we applied the mashed avocado to the trays. Once we had mashed the avocado, we strained it through the mesh that we had used for the bottom of the trays, ensuring a more even consistency on the trays.



Figure 23. Setup of tray covers experiment

We left soon after setting up this experiment, so we were unable to observe the results ourselves, but three of our community partners (Penuel, Jonah, Steven) came to visit us several days later and told us that the black plastic performed the best. The avocado that was dried on the metal sheet did not produce any oil when pressed, potentially because it got too hot, causing the oil to evaporate. It is possible that the metal sheet expedites the drying process and therefore avocado dried on the aluminum needs to be removed from the dryer more quickly, but we cannot be sure with the information we were given. They did not notice a difference in drying speed or oil quality between the upper and lower trays. Samples from all of the avocados involved in this set of experiments were pressed (Figure 24). They pressed each sample and then labeled them according to the experimental conditions. They rinsed out old medicine bottles and used them as air-tight storage for the oil. The 3rd sample, seen below, just contains water. We intend to test this water to see whether they were able to rinse out all of the residue from the medicine bottles.



Figure 24. Oil samples from various dryer configurations

Table 3. Drying conditions that lead to oil samples in Figure 24

	Drying Condition	Tray Covering
Sample 1	Placed in dryer with chimney	black plastic
Sample 2	Placed in dryer with chimney	clear plastic
Sample 4	Placed in dryer without chimney	black plastic
Sample 5	Placed on the ground in a tray	black plastic
Sample 6	Placed in dryer without chimney for one afternoon and then set on the roof (aprx 60 degrees C) for one morning	no covering (bare mesh)

They allowed the result of each pressing to rest before bottling, and then they collected only the top layer. The oil from sample 6 is certainly the darkest, while sample 1 is the lightest. From speaking with Anna, a woman involved in making and selling cosmetics, we have determined that color of the oil is not necessarily important. Clarity is the most important factor, as highly clear oil is indicative of pureness. All of the samples had a somewhat milky consistency. Further refinement of the oil or tweaks to the drying and pressing process could mitigate this issue, and we provide some suggestions in the future work section of this report.

Market Research

Market Research Overview:

This is the summation of the market research completed by our team in Tanzania over January 2015. We reached the following conclusions on the market for avocado oil in Tanzania.

→ Avocado oil is not available in conventional distribution channels in Tanzania. It is not a widespread type of cooking oil and thus cannot readily be found in outlets like supermarkets.

→ There is a demand for cosmetic-grade avocado oil from high-end natural product developers who procure avocado oil at high costs. These developers are interested in purchasing locally produced oil for branding reasons. At the moment, those who require avocado oil source it from neighboring countries such as Kenya.

→ Given the availability of cheap cooking oils like sunflower oil, the production process for avocado oil must be cost-effective if avocado oil is to compete in the cooking oil market as well as the cosmetic oil market.

Uses of Avocado Oil:

Avocado oil has many beneficial properties, including a high vitamin E content, which has been linked to a lowered risk of coronary heart disease, a high amount of monounsaturated fatty acids, which help to reduce LDL cholesterol, a low amount of saturated fat, and high levels of sitosterol, which is believed to depress cholesterol levels.^[2]

We have identified three separate markets for avocado oil and its derived products. There may be further unidentified markets, but we did not come across them in our preliminary research.

a. Cosmetics

Avocado oil may also be used in cosmetic products such as oil mixtures for skin-care. Buyers of avocado oil in this sector require it to be cold-pressed. Avocado has moisturizing and anti-oxidizing properties as well as a high vitamin content, which make it desirable in cosmetics. Avocado oil competes with moringa, baobab, macadamia, hibiscus and argon oil for use in cosmetics because these oils share similar properties.

b. Cooking oil

Avocado oil may be substituted for sunflower or olive oil and used for cooking. The use of moringa oil, which is generally considered comparable to avocado oil, is also becoming more widespread, but its smell is considered unpleasant by some and could therefore limit its penetration into the cooking oil market. Avocado oil's high vitamin content could also give it a competitive advantage against olive oil.

c. Soap

Low-grade avocado oil may be processed into soaps. This market has been mentioned, but it has not been thoroughly researched.

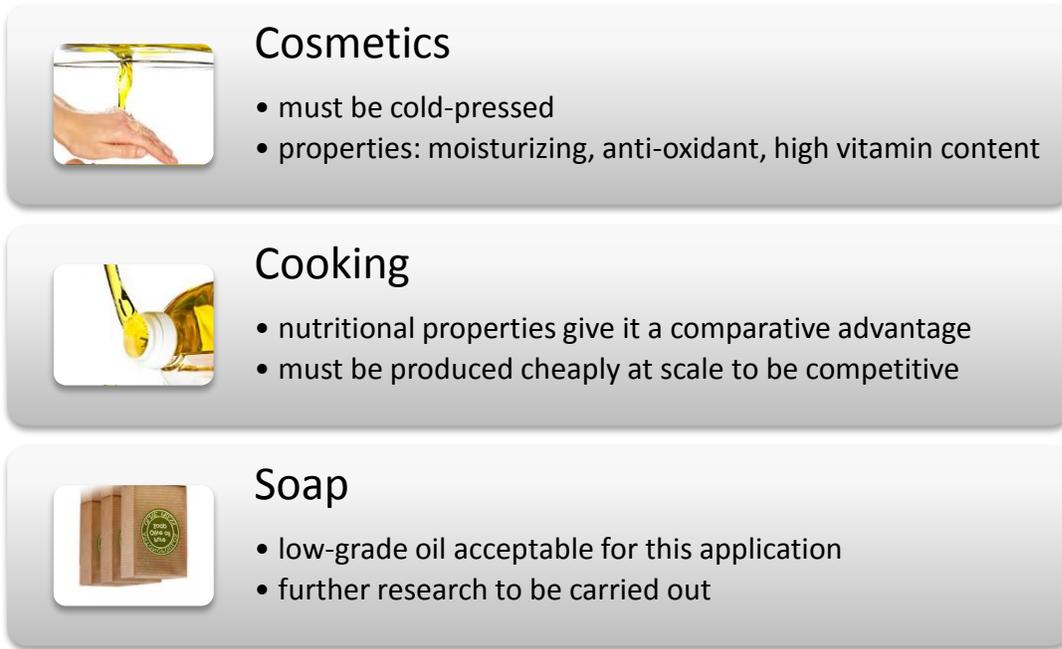


Figure 25. Overview of Market Requirements for Cosmetics, Cooking, and Soap

Niche demand within a generally uninformed market

Though avocado oil is not available in conventional distribution channels such as supermarkets, we have identified individual niche buyers who require avocado oil and are procuring it internationally.

During our short stay in Arusha, we identified and engaged with two examples of individual niche buyers. The first is Anna, a Russian expatriate married to a UN diplomat, who develops products for cosmetics and skin-care. This is the Anna that stressed the importance of clarity over color. She said she would be willing to pay 40,000TSH per liter of pure avocado oil.

The second is Lesley, the owner of “Meat King,” who manages the local branch of a business selling mostly high-end dairy products to foreigners living in Tanzania. She generally purchased 50 100ml bottles of avocado oil every 4 months for 4,000TSH per bottle. She said that this

supply was generally not enough to keep up with the demand from her customers. Elliot mentioned that Meat King is a very powerful and influential company in Arusha, so a connection with them would certainly be beneficial.

These examples suggest there is indeed a local demand for high-quality avocado oil which is not currently being met by supply, which means that there is market opportunity.

Market Opportunity:

We believe there is a market for high-grade avocado oil in cosmetics for the following reasons:

- Both buyers that we spoke with outlined the **complex logistics** involved with sourcing their avocado oil, which makes the possibility of a local supply appealing to them.
- **The price** that these buyers are ready to pay for avocado oil suggests there is a market for avocado oil in high-end applications. Using a price-based pricing strategy (setting the price of a product according to what consumers have said they would be willing to pay for it), the avocado oil producers should be able to enjoy healthy margins on oil sales.

In Dar, We had a meeting with, Twahir S. Nzallawahe, the Director of Crop Development for Tanzania. He has started producing avocado oil as a business. He has about 1,200 avocado trees, and produced 700L of oil this, his third, season. He sells 400ml for 11,000 TSH, which is consistent with other pricing information we have received. His business has grown via word of mouth, and his supply does not yet meet the demand from his customers.

Whether there is a market for avocado as a cooking oil remains to be determined. Sunflower oil can be bought as low as 21,000 for a bottle of 3L. We are therefore unsure whether avocado oil

can be competitively priced and penetrate the market. The production process chosen to produce the oil will determine whether using avocado oil as a cooking substitute is feasible. Further research should be done.

Business Plan Template: Large-Scale Possibilities

We lack data on the state of play for the macroscopic national avocado oil market to produce a fully-formed business plan, so we have created a recommended template. The following business plan is therefore only a template; it can be completed when data on market size is gathered. The template, however, is not generic, as it has been constructed specifically for this project.

Market Sizing Integration Calculations:

a. Market segmentation

- Cosmetics (**Market A**) require the highest grade oil.
- Cooking Oil High Temp (**Market B**) is avocado oil that is produced from avocados that were dried at a high temperature. Drying at a high temperature degrades the quality of the oil, which means that it can be used for high-temperature cooking without further decreasing nutritional value.
- Cooking Oil Low Temp (**Market C**) includes cold-pressed oil. Cold-pressed oil has a higher nutritional value and is higher quality than cooking oil high temp.

b. Demand per market (Volume)

- Number of potential buyers in Arusha:

What volume ?

Insert supporting data

- Number of potential buyers in Dar es Salaam:

What volume?

Insert supporting data

→ Extrapolation to potential volume at national level.

c. Price point per market

Market A - Price : \$X /L

Insert supporting data and surveys

Anna : currently paying \$50k / L , looking for \$30k – 40k /L

Lesley : same supplier as Anna

Market B - Price : \$X /L

Insert supporting data and surveys

Market C - Price: \$X /L

Insert supporting data and surveys

d. Demand requirements: Minimum Viable Product (MVP)

Ex. Quality?

Market A –

Market B –

Market C –

Venture targets:

TBD - What do producers actually want to do with the oil?

Ex. Meet 10% of local Tanzanian demand for avocado oil

Costs:

- a. Raw upfront costs:
 - Building supplier relations
 - Infrastructure
 - Equipment
 - Machine costs
 - Workshop space [breakdown for different activities]
 - Space required: X m²
 - Cost to use space: \$X / m²

- b. Operational costs:
 - Labour:
 - N of employees:
 - Pay / employee / day: \$X → Pay / employee / year: \$X
 - Delivery & SC Logistics
 - Running costs (energy, rent of equipment)

- c. Additional cost complexities:
 - Gearing towards export
 - Marketing costs (initial market penetration and operational)
 - Distinction between MVP and additional characteristics
 - Take competition into account
 - Margins
 - Funding sources
 - Development agency
 - Local VC
 - American VC
 - Prize money

Break-even time:

$$\text{Profit} = (1 - \text{Tax}) * (\text{Revenues} - \text{Costs})$$

[Cash flow bar graphs]

Discount rate chosen: *what rate of return do investors expect from the venture?*

Initial investment: \$X

Break-even point / Pay-back time = X years

Small scale market: Leguruki

The majority of the above content on the market for avocado oil was collected in a conventional way and applied to a Western-style business plan. A growing business in the developing world is bound to encounter different expenses and challenges.



Figure 26. The center of Leguruki is marked by a field ringed with shops.

Avocado oil may become a substitute for other cooking oils in the village, thus slightly improving the livelihoods of the people of Leguruki by decreasing what they spend on cooking oil. Avocado oil may not have any potential as a product in the wider country-market, but something we observed from working in Leguruki is that the success of the project will depend largely on the human dynamics in the community. At the moment, the project is led by two influential members of the



Figure 27. Pastor Emanuel discussing dryer design with his fellow wood-fundi

community: Pastor Emmanuel, and Penuel (both described in the Community Partners section of this paper). Penuel, for instance, succeeded in summoning a small group of farmers to a wrap-up meeting we held on our final day in Leguruki. Pastor Emmanuel is also an influential figure; following his impulse, many farmers in his community planted large numbers of avocado trees twenty years ago. We also noticed the pastor's great local influence on the day that we hired him to help build the dryer, as he came with 4 other wood-fundi that we were not expected to pay.

A project's success in a village like Leguruki is largely dependent on its leader. The observation that Penuel and the pastor are influential figures makes us believe that if they were to produce avocado oil at a comparable price to the sunflower oil that the people of Leguruki typically use for their cooking, this new kind of oil would be adopted locally and penetrate this small-scale market. The pastor and Penuel have both been involved with the project before and during our stay, so we can assume that their continued interest in the project is possible and even likely.

If they succeed in penetrating the small market, they can consider a larger venture for avocado oil in the nation-wide domestic market.



Future Work

From consulting our community partners and our own observations, we have made some recommendations for changes to our dryer design, which we will present here. We liked the use of mesh in the tray design, and based off of the experiments carried out in Leguruki, we suggest using black plastic as a cover for the mesh. The addition of adjustable, wooden tray supports would solve the issue of the avocado mash sliding off of the plastic. Making the tray adjustable would also allow the people in Leguruki to run tests at different tray angles without building an entirely new dryer. Adding a hinge and several notches in the tray supports on the inside of the

dryer would make this adjustment possible (See Figure 28). We also agreed that a fan, whether it be solar-powered or connected to the grid, is necessary, as ventilation is crucial to the drying process. The fan could either be placed before or after the sheet of aluminum metal (See Figure

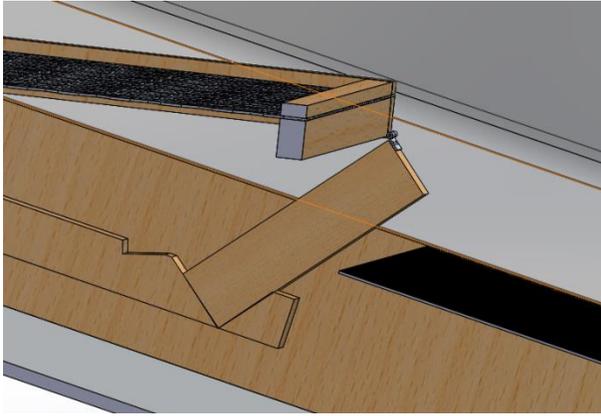


Figure 28. Adjustable tray slots incorporated into final design

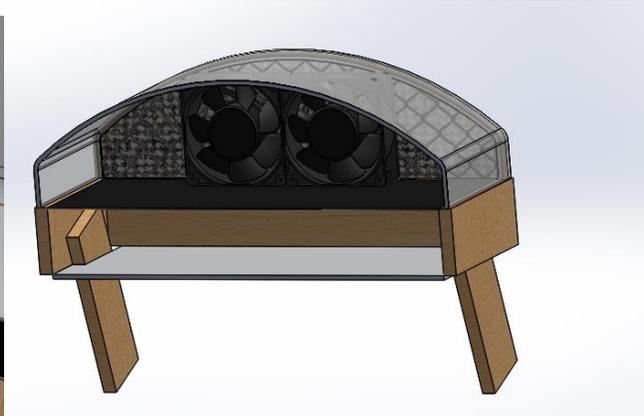


Figure 29. View of proposed fan(s) and moisture shield

29). We are unsure which position would be most effective, so this decision becomes one of practicality and experimentation. The use of a fan obviates the need for a chimney. We also think that some type of humidity shield would be useful, as the air during peak avocado season can be quite humid. One possible idea for this humidity shield could involve dispersing rice throughout a porous material like wool, and then clamping the wool between two layers of mesh. The humidity shield should be placed at the entrance of the dryer instead of the mesh covering that was used in Figure 18 and Figure 21. The fan can be placed on either side of the shield based on convenience.

Instead of having black plastic covering the length of the dryer's underside, aluminum could be used, which would allow people to burn biomass under the dryer in winter months when sunlight is not as readily available. During a cloudy interval, the specific heat capacity of the aluminum would allow the heat of the metal, originating from the burning biomass or from thermal storage, to diffuse into the dryer, which is how additional heat could be provided. We

are not sure how the fire can best be contained, but we believe the village members are savvy enough to find a practical solution. The height of the iron rods should be adjusted according to the size of the fan being used, as we think a fan of the size of the dryer's opening would be optimal.

Figure 30 is the dryer with our final recommendations. We also think that, on a sunny day, a black tarp should be draped over the back two-thirds of the dryer so that we can see how oil quality is altered by having the avocados subjected solely to hot air rather than to hot air and direct sunlight.

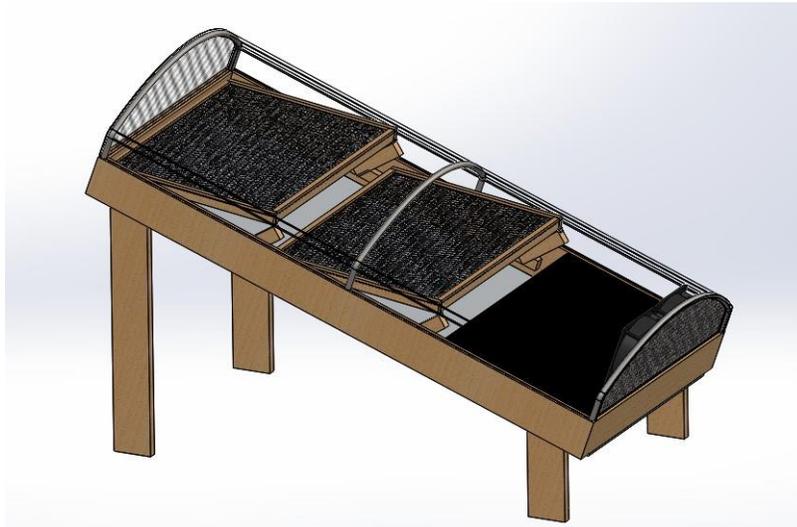


Figure 30. Dryer design with incorporation of final recommendations

From speaking with purchasers of avocado oil, it is apparent that cold-pressed oil is the standard for cosmetics, moisturizers, massage oils, shampoos, and other body-care goods. We currently believe most large companies use centrifuges to extract oil from their avocados, as heating the avocado to above 50°C causes the oil to lose some of its beneficial properties, likely due to denaturing of proteins in the oil. Implementing the production of avocado oil through the centrifugation and cold-pressing is one possible future route for oil extraction from avocados in

Leguruki. We have discussed this possibility with most of the key community members (Penuel, Pastor Emmanuel, Yonah), and they have all been interested in and receptive of the idea. Centrifugation involves mashing avocados into a paste and feeding the paste into a centrifugal decanter which separates oil from the water and flesh.^[3] Highest oil-recovery percentages have been obtained from centrifuging at 12,300 xg.^[4] While this is the speed that has been shown to produce the maximum amount of oil, we would be interested to know what the minimum allowable speed is that would still produce a good oil yield. Cold-pressing can involve a three phase decanter that separates mashed avocado into oil, water and solids.^[3] It is our understanding that avocados dried below 50 degrees C meet the standards of cold-pressing, perhaps making “cold-pressing” more of a general idea than a specific process. The few companies that we researched were all extracting avocado oil via some form of centrifugation. The advantages of using centrifuges exclusively are that the process is much less weather-dependent than solar drying and that by avoiding exposing the avocados to sunlight nor heat, the process produces the highest-quality oil. However, it is unlikely that Leguruki has the capacity to meet the energy input requirement of a large centrifuge. With this challenge in mind, we recommend that explorative work be done on designing a low-power centrifuge that is suitable for avocado oil extraction.

Conclusions

The dryer design experienced much change as we gathered more information through experimentation, research, market research, observing the availability of various materials, and discussions with our partners. Through the design process, we have tried to keep our minds open to new design ideas and different opinions.

Perhaps the most important point to keep in mind is that any dryer should aim to work better than the current drying method, which is a tarp on the roof. We have found that ventilation is actually much more important than temperature. Temperatures that are too high degrade the quality of the oil and can lead to case hardening. The current avocado oil market calls for cold pressing, meaning that oil must be extracted using temperatures no higher than 49 °C. Filtering the avocado by passing it through a mesh or some similar material before spreading it onto trays improves the drying process, as chunks of avocado flesh can hinder the drying process. It is also important to highlight that the Leguruki locals are highly skilled in wood and metal working; our main purpose was to provide general design ideas and momentum to the project. Consulting the locals to solve practical problems is much more efficient than trying to manage every issue ourselves.

Due to time constraints, we were unable to complete ample research on local innovation in Leguruki. As we close this report, we think it is still appropriate to reflect on what our involvement in this project has taught us about local innovation processes. Through our observations of innovators that had been identified during IDDS and of innovators that we connected with during our field work, we constructed a set of traits characteristic of local innovators. We realize that we do not have enough data points to make claims, so these are merely observations. We noticed that the innovators we interacted with were reserved in speech, took great pleasure in showing their work to visitors, readily challenged new ideas we put forward, and showed confidence in their own designs. They preferred to build and experiment rather than draw and discuss. We also noticed that the innovators we met had other full-time occupations. They are not “resident entrepreneurs” or innovating for a living. They were

generally reliant on outside sources of funding for their projects. Elliot, for example, was helping Penuel fund his press work by assisting him in applying for pico-grants.

Finally, we identified some limitations of the current local innovation processes. For instance, the innovators we met had not developed automatisms to test their ideas and did not use rapid prototyping before carrying out a full build of the design they envisioned. Penuel, for example, came to us with the sketch of a design that he had considered building. He did not think of attempting a proof of concept for the idea or testing individual elements of the design. This meant that the amount of resources he believed necessary to carry an idea forward were high, whereas a small investment could have been sufficient to scope out the idea and test its true potential. The general attitude in Leguruki was that a product should be completely finished before it is evaluated. We feel the community learnt from our methods, however, as some of our partners have spoken with us about their ideas for future experiments, which hints at a shift towards a more methodical approach to design, which may have more wide-spread implications.

Contrary to our initial perception, the drivers of this project are visionaries who are more interested in producing high quality oil than in creating a very low cost dryer, perhaps making a centrifuge a more appropriate option than a solar dryer. By co-creating the dryer with Penuel, Pastor Emanuel, and others in central Leguruki we were able to garner interest from various farming groups around town and develop many connections between the different community partners. Although the project has a long way to go before Leguruki farmers can start producing quality avocado oil at scale, our stay helped lay the foundation for continued progress by rekindling the innovative spirit started during IDDS within many community members across Leguruki.

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