Cassava Flour Production
For Small-scale Farmers

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Executive Summary

With the end goal of increasing the shelf life of the cassava root, a process and devices were developed to convert the root into flour. Shelf life of the flour is 3 to 6 months compared to the 3 days before deterioration begins on the raw root. Decreasing spoilage means larger food supplies and potential income from sale of excess. Special care was taken to assure the process would produce cassava flour that had cyanide equivalency levels within the World Health Organization threshold of 10ppm. Bacterial contamination and aflatoxin growth were taken into consideration and the details of the process are aimed at reducing both. Multiple designs were synthesized and analyzed to determine which completed the end goals and design parameters best. All developed devices are human powered, low cost, and easily remanufactured.
Introduction

“We cannot solve our problems with the same thinking we used when we created them.” As this quote by Albert Einstein illustrates, it is improbable that innovation will come about by fixating on the past with a defeatist mindset. Forward thinking is required to discover solutions to current problems. Many Kenyans today face problems such as poor living conditions, inconsistent food sources, and a lack of micronutrients which cause problems such as stunted growth and malnutrition. However, a popular dish in many parts of Kenya is Ugali. Ugali is a food with a consistency similar to that of porridge, it is often made with maize. Stable food sources such as cassava (which can also be used in traditional dishes such as Ugali) are eaten by a vast majority of the Kenyan people, and is a major staple in many Kenyan diets.

Today in Kenya, the cassava plants plagues the vast majority of farmers. Cassava is a tuberous root from a tropical tree. It looks much like a sweet potato, only larger. However, the problem does not lie in the plant itself but instead in the short shelf-life that the raw plant has due to postharvest physiological deterioration (PPD). Once harvested, the cassava root begins to break down within 72 hours, and the crop is soon considered unusable. The plant also contains cyanogenic glycosides which are converted into cyanide in the digestive system. These toxins must be properly handled during processing to prevent ingestion of unsafe levels of cyanide, which can result in things such as paralysis and even death.

This report covers the development of a process and device that will allow the cassava root to be easily and quickly converted into a safe, more stable form. The goal is to lengthen the shelf-life of the cassava root from 72 hours to 3-6 months by processing the root into flour. This device will be solely human-powered, and the process will assure the toxins within the root are brought to safe consumption levels regardless of plant variety. Because of the longer shelf-life of the flour as opposed to raw cassava root, food supplies will be increased by reducing the spoilage caused by PPD. This will not only give
families access to more food throughout the year but increase the annual income of small scale farmers as more product can be sold due to decreased waste.

Though the initial area of concern for this project is rural Kenya the goal is to develop a process that can be used universally with any variety of cassava in any region thus furthering and increasing the benefits of the work done and the effects it can have on those who need it most.

About Cassava

Cassava is a starchy tuberous root from a tropical tree. An illustration of this tree and the cassava root can be seen in figure 1. Cassava plants are very resilient and mostly self-sufficient after about the first 6 weeks of life. This means that the plant can survive with little water and in soil that is not extremely fertile making it an excellent crop for regions without perfect agricultural conditions. Because of its resilience and high carbohydrate content it is commonly used as a food source in tropical and poorer regions.

Figure 1 – Cassava tree and root illustration
Cassava toxicity is one of the biggest downsides to the crop. Cassava plants contain cyanogenic glycosides (Linamarin and Lotaustral). Depending on the variety of the cassava plant the amount of these toxins vary. Cyanogenic glycosides are a plant defense mechanism to prevent the plant from being eaten. As the plant is macerated the toxins are converted into hydrogen cyanide. Conversion to cyanide can also happen when the toxins come into contact with gut flora found in human intestines. Excess cyanide ingestion can result in things as serious as death, paralysis, and loss of vision and for that reason it is crucial that these toxins are removed from the plant. One way to remove the toxins is to convert them to hydrogen cyanide in a controlled fashion outside of the human body. When the cyanogenic glycosides are combined with an enzyme that naturally occurs in the cell walls of the plant. This enzyme is released by breaking down the cells which can be done through a process like grating. The more the plant is cut up the more of the enzyme is released and the more intimate the contact between the toxin and the enzyme is which will allow for the toxin to be converted to hydrogen cyanide. Figure 2 shows the chemical reactions that take place to convert Linamarin to hydrogen cyanide.

![chemical reaction diagram]

Figure 2 – Chemical explanation for conversion of linamarin to hydrogen cyanide
It should be noted that the hydrogen cyanide could become gaseous depending on the temperature. The vaporization temperature for hydrogen cyanide is 78.0 to 79.8 °F. Temperatures in Kenya are right around this point (figure 3). Because of this the process should be done outdoors or in very well ventilated areas. The water coming from the cassava should not be used for anything. It should be disposed of in a charcoal pit. Drinking or otherwise ingesting the water could result in the same cyanide related diseases mentioned earlier. Table 1 shows an analysis of waste water from cassava processing from M. P. Cereda et al. This table shows a very high amount of hydrogen cyanide.

Figure 3 – Annual weather data for Kenya, Africa

Table 1 – Average cassava liquid waste content

<table>
<thead>
<tr>
<th>LIQUID WASTE</th>
<th>Humidity %</th>
<th>93.71</th>
</tr>
</thead>
<tbody>
<tr>
<td>% on Dry Matter</td>
<td>Protein (6.25)</td>
<td>0.49</td>
</tr>
<tr>
<td>Starch</td>
<td>Carbohydrate</td>
<td>-</td>
</tr>
<tr>
<td>Lipid</td>
<td>Ash (500°)</td>
<td>1.06</td>
</tr>
<tr>
<td>pH</td>
<td>Fibers</td>
<td>-</td>
</tr>
<tr>
<td>Acidity*</td>
<td>HCN(p) mg/l</td>
<td>444.00</td>
</tr>
<tr>
<td>(p) Potential</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average min and max temperatures in Nairobi, Kenya. Copyright © 2015 www.weather-and-climate.com
Problem Statement

Before creating our design specification, we made sure to fully define the problem. This allowed us to look at each of the design parameters and decide which were most important and which were the least important. As shown below in a bulleted list is what we determined the problem and requirements to be:

- Conserve the product.
  - Minimize waste / reduce spoilage
  - Develop a process that will eliminate wastes due to crop spoilage
  - Extend the shelf life from 3 days to at least 6 months
- Process 10-15 metric tons of cassava annually per hectare. This generally happens over a four-month period.
- Dry cassava to critical moisture level (12%) within 3 days. (Shorter time is better)
- Optimal chipping/ grating design that allows for most amount of cassava to be processed in the time frame
- Designs that can be reproduced by non-engineers with local materials
- Eliminate toxins in cassava that result in cyanide (lethal dose of CN- is 1 mg/kg)
- Develop a drying process that eliminates bacterial growth
  - Shorter drying time in certain conditions reduce the risk of mold
- Should not cause bodily harm to operators
- Design devices that will last for long periods of time without malfunctioning
  - Device should not require servicing more than once a year
- Produce high quality cassava flour
  - Final product must be useable and valuable

From the problem definition we were able to examine the individual design parameters and determine their importance for our particular project. The rest of the report contains a ranking and thorough examination of the design parameters.
Design Parameters

The design parameters below were examined and evaluated with respect to the project and each was given a ranking of importance between 0 and 3. The value to importance relationship is displayed in table 2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements which are essential</td>
<td>3</td>
</tr>
<tr>
<td>Requirements which are highly desirable</td>
<td>2</td>
</tr>
<tr>
<td>Requirements which are desirable</td>
<td>1</td>
</tr>
<tr>
<td>Requirements which are almost irrelevant</td>
<td>0</td>
</tr>
</tbody>
</table>

Function/Performance (3): This is one of the most important design specifications that needs to be considered. The design is created to perform a function, in this case, grate and chip cassava, and if it cannot do that, then the entire machine is defunct. While the primary function of the Cassava machine is to grate/chip cassava, the performance of the machine may be considered a secondary function. The design must perform at high enough standards that the human-powered effort put into the machine is not considerably above the average effort that could be used to complete the same process by hand. If the machine performs so poorly that it would be easier or quicker to just chip/grate the cassava by hand, then it also is not performing the function it was designed for.

Product Cost (2): Normally product cost would be a major design consideration if not solely to make profit for the company. While this is a highly rated consideration for this project, the goal is not to profit off the design, but rather to make it low-cost enough to be easily reproducible. With the low income area that this device is destined for, limiting the product cost is strongly desired.
Quantity (3): The quantity is an important design specification even though the quantity is only one finished device. If the quantity is any less than this, then the project could be deemed a failure. This device is also expected to be shipped, and with only one machine that is most cost affordable. A positive aspect of having a small batch size, in this case, extremely small, is that general-purpose machine tools and processes will be employed to make parts from standard stock materials.

Manufacturability (3): Manufacturability design specification is very important in this project as the design group are not the only ones expected to manufacture this device. This device will be designed-for-manufacture by someone who doesn’t have access to unlimited machining tools and materials. This is an important design specification to keep in mind when it comes to selecting materials and equipment. If part of the manufacturing process involves using a complex machine to create a part, the manufacturability of the device will suffer. Therefore, great consideration must be given to how the device is created and assembled.

Safety (2): Safety of the people operating the device is obviously a big concern when it comes to the design specifications. It may be adults or younger children working the machine and avoiding dangers for everyone is very important. The biggest concern is taking care of the potentially hazardous cyanide that is found in the skin of the Cassava, most of which is removed in the skinning process. In order to make the device as safe as possible, any moving parts or potential catches for clothing should be insulated from the user by guards, sharp edges should be rounded off, and safety interlocks should be implemented where necessary.
Quality (2): This specification does have its importance within the machine; however, it will be more practical if more important specifications were addressed first such as performance. Quality can be more easily addressed after the construction of the machine, which is simply the process of improving and perfecting the performance of the machine.

Maintenance (1): Given that this machine must maintain itself for several years without maintenance, it is not an important aspect that should not be as focused as other important design specifications such as performance. Once the design specifications for service life and reliability are addressed and resolved, there will be clear direction on how this specification can be address.

Service Life/Reliability (2): The machine must be reliability enough for farmers to process a large quantity of cassava in a timely manner, and it must have a service life that can last for several years without maintenance. The completion of the machine must be done first in order to measure and increase its reliability and service life.

Operating Instructions (1): Given that the assembly of this machine must be constructed with the resources accessible to farmers; the operations of it must be simple enough that it is self-explanatory. Therefore, the operating instructions should not be addressed with the upmost importance.

Health Issues (3): Cassava already has a toxic element that is dangerous to the human body. Even though it will be cleansed and purified for human consummation, contaminating elements such as rust, could be instilled within the crop during the processing. As such the design
must not rust, or generate any other contaminating elements, during the cassava processing or else it will be unsafe for human consummation.

**Human Factors/Ergonomics (2):** Device should be able to be operated by an individual with minimal effort, and should not require any special training in order to operate. When operated, it should not cause the operator any unnecessary distress and should not be uncomfortable to use.

**Energy Consumption (1):** Operating of the device should be done by human means only, with no outside energy sources contributing to the final output of the device. Device should work in a way that will allow for the operator to put in as little effort as possible in order to achieve the desired results.

**Operating Costs (1):** Cost to operate this device should be $0 for a considerable time after the completion of the initial device. Initial cost of the device should be kept as low as possible in order for the device to be afforded by more people throughout the region.

**Environmental Conditions (2):** Device should be able to operate in areas of high heat and humidity. Dust and other debris should also not hinder the devices operation.

**Weight (0):** Weight of the completed machine should be one that allows for the contraption to be moved if needed, or be disassembled to allow for easier transportation by the individual or family.
**Size (0):** Spatial constraints of device should lie in a reasonable space. However, the device should be large enough in order to be operated easily by the operator, all while achieving the overall goal of the device.

**Process Development**

Given the serious side effects and health risks associated with human ingestion of cyanide, care was given to develop a process that produced safe cassava. Figure 4 shows a distribution curve of the total cyanide over 119 flour samples in Mozambique. Mean total cyanide value from this data was 41ppm. The World Health Organization (WHO) has set the safe threshold for cyanide at 10ppm. This shows that many of the current methods for producing cassava flour do not produce a safe end product. This prompted further research into the individual methods to see which was most effective at removing cyanide.

![Figure 4 – Distribution curve of total cyanide content over 119 flour samples in Mozambique](image-url)
Tables 3 and 4 show data from analysis of many cassava samples processed using different methods to determine which process most effectively removes cyanide. Both sets of research show that grating is an effective method at removing cyanide. They also show that soaking removes as much if not more (per the research shown in table 4) but because of the lack of clean water in the region in question grating was chosen as the best possible option for producing a safe product. Grating is effective because it assures adequate break down of cell walls which allows enough enzyme to be released to convert the toxins to hydrogen cyanide. It also promotes intimate contact between enzyme and toxin.

### Table 3 – Cyanide removal for individual processing methods

<table>
<thead>
<tr>
<th>Processing method</th>
<th>Countries of use</th>
<th>Estimate CNp removal (%)</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling of fresh roots</td>
<td>All country that use cassava as food</td>
<td>25-65</td>
<td>Nambisan &amp; Sundaresan (1985) Cardoso <em>et al.</em> (2005)</td>
</tr>
</tbody>
</table>
Table 4 – Calculation of maximum root total cyanide levels (ppm), using a particular processing method, that will lead to safe cassava products

<table>
<thead>
<tr>
<th>Processing method</th>
<th>Name of product</th>
<th>% retention</th>
<th>Max. root total cyanide levels (Rmax) using processing method shown, to fall within less than</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 ppm (WHO)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>40 ppm (Indo.)</td>
</tr>
<tr>
<td>Sun drying</td>
<td>Flour</td>
<td>25–33&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>12–16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>48–64</td>
</tr>
<tr>
<td>Heap fermentation</td>
<td>Flour</td>
<td>12.5–16.5&lt;sup&gt;c&lt;/sup&gt;</td>
<td>24–32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>96–128</td>
</tr>
<tr>
<td>Soaking &amp; sun drying</td>
<td>Lafun/fufu</td>
<td>1.3–2.2&lt;sup&gt;d&lt;/sup&gt;</td>
<td>181–308</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>727–1230</td>
</tr>
<tr>
<td>Soaking, fermentation &amp; roasting</td>
<td>Farinha/gari</td>
<td>1.8–2.4&lt;sup&gt;e&lt;/sup&gt;</td>
<td>167–222</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>667–889</td>
</tr>
<tr>
<td>Crushing &amp; sun drying</td>
<td>Flour</td>
<td>1.5–3.2&lt;sup&gt;b,f&lt;/sup&gt;</td>
<td>125–267</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500–1066</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mlingi and Bainbridge (1994).
<sup>b</sup>Nambisan and Sundaresan (1985).
<sup>c</sup>Heap fermented flour normally contains about one half the total cyanide compared with sun dried flour (Essers et al., 1995; Cardoso et al., 1998; Ernesto et al., 2000, 2002a).
<sup>d</sup>Oke (1994).
<sup>e</sup>Dufour (1994).
<sup>f</sup>Nambisan (1994).

Cyanide is not the only health factor that affects aspects of the process. Bacterial and mold growth were also taken into account and researched. Mold growth is a concern when fermenting processes are used or when the root is not dried out in a timely fashion. The stages in the process prior to final drying should all take place in succession without waiting in between. This removes the chance of mold growth. 12% is the desired moisture content. Drying and storage methods also play a role in aflatoxin growth. Table 5 shows aflatoxin levels through comparisons of processing, drying, and storage methods. The data is a Poisson regression analysis of aflatoxin levels in cassava samples. Drying cassava on tarpaulin would lead to 22 times less contamination compared to drying otherwise. Storing in polypropylene bags lead to the least amount of contamination.

Table 5 – Association between aflatoxin levels and processing, drying and storage methods in cassava samples (R<sup>2</sup> (Adg) = 13.1%, F = 9.26, p>F = 0.004)

<table>
<thead>
<tr>
<th>Processing, drying and storage methods</th>
<th>Coefficient (β)</th>
<th>Bootstrap p Std Err.</th>
<th>Z</th>
<th>P&lt;z</th>
<th>p = 100&lt;sup&gt;*f&lt;/sup&gt;[e-1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fermenting cassava (X1)</td>
<td>-0.017</td>
<td>0.012</td>
<td>1.39</td>
<td>0.165</td>
<td>1.7</td>
</tr>
<tr>
<td>Slicing (X2)</td>
<td>-0.106</td>
<td>0.055</td>
<td>-1.92</td>
<td>0.055</td>
<td>-10.0</td>
</tr>
<tr>
<td>Drying on bare ground (X3)</td>
<td>-0.162</td>
<td>0.100</td>
<td>-1.63</td>
<td>0.103</td>
<td>-15.0</td>
</tr>
<tr>
<td>Drying on bare rock (X4)</td>
<td>-0.207</td>
<td>0.130</td>
<td>-1.59</td>
<td>0.112</td>
<td>-18.7</td>
</tr>
<tr>
<td>Drying on tarpaulin (X5)</td>
<td>-0.250</td>
<td>0.124</td>
<td>-2.02</td>
<td>0.043&lt;sup&gt;*&lt;/sup&gt;</td>
<td>-22.1</td>
</tr>
<tr>
<td>Drying on paved surface (X6)</td>
<td>-0.260</td>
<td>0.129</td>
<td>-2.02</td>
<td>0.043&lt;sup&gt;*&lt;/sup&gt;</td>
<td>-22.9</td>
</tr>
<tr>
<td>Storage in polypropylene bags (X7)</td>
<td>0.148</td>
<td>0.038</td>
<td>2.55</td>
<td>0.011&lt;sup&gt;*&lt;/sup&gt;</td>
<td>15</td>
</tr>
<tr>
<td>Storage in Jerricans (X8)</td>
<td>0.289</td>
<td>0.143</td>
<td>2.02</td>
<td>0.043&lt;sup&gt;*&lt;/sup&gt;</td>
<td>33.5</td>
</tr>
<tr>
<td>Storage on bare floor (X9)</td>
<td>0.176</td>
<td>0.074</td>
<td>2.37</td>
<td>0.018&lt;sup&gt;*&lt;/sup&gt;</td>
<td>19.2</td>
</tr>
<tr>
<td>Constant</td>
<td>0.284</td>
<td>0.063</td>
<td>3.05</td>
<td>0.003&lt;sup&gt;*&lt;/sup&gt;</td>
<td>32.8</td>
</tr>
<tr>
<td>Number of observations</td>
<td>55,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

g: Estimated effect of a unit change in variable X.; *Effects were significant (p ≤ 0.05)
With the previously described research in mind the process laid out in figure 5 was developed. This process will result in the largest reduction in cyanide levels without using water in any manner (because of lack of the resource and added risk of aflatoxin growth).

![Flowchart of desired cassava flour production process](image)

**Figure 5 – Flowchart of desired cassava flour production process**

**Conceptual Designs**

**Introduction**

Design concepts for each device were developed to solve the previously described problems and meet the design parameters. Each of the designs will incorporate figures and schematics in order to better understand their functionality. Each conceptual design will be categorized and separated under either grating, pressing, or milling. Grating is the aspect of reducing cassavas as a whole into smaller bits...
so that the pressing, or the dehydration, aspect is easier to do. The pressing aspect involves gathering these smaller bits into a grated mesh and then insert a force downwards upon it to remove the moisture. Milling is the aspect of reducing cassava bits even further into smaller particles that’s ready for screening. There is no unique parameter for each category, but each conceptual design is based on their manufacturability and efficiency. Our group has chosen this approach so that the assembly of this device can be easily done with the resources and tools accessible to Kenyan manufacturers.

**Grating**

**Moving Hopper**

One possible design for the grating process is using the box a sliding crank. The box is a housing mechanism that houses cassavas as it moves back and forth on the stationary grating surface. This motion will force the cassavas into the same motion. The motion of the box is done by a set of a bicycle chain and petals attached to a gear. This gear will be attached to linkages that are also attached to the box.

![Moving hopper grating schematic](image)

**Figure 6 – Moving hopper grating schematic**

**Pros:**

- Human-powered
- Only one person to operate
Components are easily accessible and manufacturable

Cons:

- Force required to operate may vary
  - dependent on the ease of grating multiple cassavas
- Cassavas are just moving back and forth, not downwards on the grating surface
  - An solution to insert a weight on top of the hopper and have that weight push the cassavas downwards
- Complicated production of sliding interface
- Part of the grater surface may be located outside.
- May be pinch points as the hopper slides back and forth
- Working against friction
- Have to move the weight of the cassava every stroke
  - More energy input required
- Would need a larger outer housing
  - For safety
  - To reduce product loss
- Only one direction of the stroke is doing no grating
  - Half the input is not grating

Drum Hopper Cylindrical Grater

This design incorporates a similar design as the Moving Hopper, but the grating surface is rotating in a circular motion while the hopper remains stationary. Once grated, the cassavas exit the hopper through a chute. The rotation of the grater is done by a set of a bicycle chain and petals turning gears at the bottom of the shaft, where it rotates the grating surface.
Pros:

- Most components are easily accessible
- Human-powered
- One person is required to operate
- Easily produced grating surface
- Easy to move product from beginning to end

Cons:

- Shaft will deform quickly due to massive amounts of cassava grating
  - An alternative includes placing shaft on top of the hopper instead
- No weight that forces cassavas downwards, results in cassavas spinning in a circle
  - Alternative addition includes stationary fins or section dividers on the inside of the drum to minimize the amount of movement
• Requires bevel gears
  ○ Harder to acquire/more expensive
• More complicated mechanically as a whole
• Grating surface would be support a lot of weight
  ○ Need to avoid deformation
• Requires a tight tolerance between wall of hopper and grating surface

**Sliding Grater Sheet**

This concept is essentially the opposite of the moving hopper design. In this design the hopper is stationary and the grating surface slides back and forth. Again in this design, the grating surface is essentially a slider crank attached to what would likely be a bicycle tire that was driven through gears and a chain connected to a bicycle pedal crank assembly. Gear ratios would be dependent on the weight that would be within the hopper at any given time and the throughput required based on device size.

![Sliding grater sheet concept schematic](image)

**Figure 8** – Sliding grater sheet concept schematic

**Pros:**

• Human powered
• Easier to produce a flat grating surface
- Easily accessible components

**Cons:**

- Part of the grater surface may be located outside.
- May be pinch points as the hopper slides back and forth
- Working against friction
- Would need a larger outer housing
  - For safety
  - To reduce product loss
- Only one direction of the stroke is grating
  - Half the input isn't grating

**Dual Drum Grater**

A dual drum grater consists of two identical cylindrical grating drums. The length of these grating would be determined through calculations of the amount of cassava that needs to be produced in a set time frame. The entire surface area of these drums would have a conventional grating type surface. The drums would be housed within a sheet metal containment unit which mainly consisted of a hopper and a discharge chute. A pedal system would connect to the main drum through a gear and chain system. The gear ratios of this chain drive would need to be determined based on the length of the drum, required throughput, and considerations of human energy consumption. The secondary drum would be connected to the main drum through an inverting gear. This would force the secondary drum to rotate the opposite direction of the primary drum.
Figure 9 – Dual grating drum concept schematic

Pros:

- Oppositely rotating drums would pull the cassava down
- Simple frame and containment unit to manufacture
  - Easily accessible materials
- Parts that could hurt someone severely are located within the containment unit

Cons:

- Manufacturing a drum shaped grater is slightly more difficult than a flat sheet
- Cassava would end up inside the drum and be difficult to evacuate
  - Increased weight of moving assembly
- Requires two drums
- Requires tight tolerances between drums
- Requires extra mechanical components to transfer rotational energy from one drum to another
● May require more input energy to achieve the same output as opposed to a single drum design

● Drums run the risk of being dented in if not properly produced and reinforced

**Single Drum Grater**

A single drum grater consists of a cylindrical grating drum whose length would be determined through calculations of the amount of cassava that needs to be produced in a set time frame. The entire surface area of this drum would have a conventional grating type surface. The drum would be housed within a sheet metal containment unit which mainly consisted of a hopper and a discharge chute. Counterclockwise rotation of the drum would be forced through a connection to a pedal system via a chain drive. The gear ratios of this chain drive would need to be determined based on the length of the drum, required throughput, and considerations of human energy consumption.

As cassava is feed into the hopper it falls between the grating surface and the wall of the containment unit. The grating drum surface cuts into and pulls the cassava into the wall as it grates it. Grated cassava then makes its way into and out of the discharge chute.

![Figure 10 – Single grating drum concept schematic](image-url)
One potential issue and a remedy for this issue is that as the cassava is grated most of it will end up within the drum. This presents the issue of getting it out and increasing the weight of the drum which is a downside for the operator. A way to fix this would be to put the drum’s axis on an incline relative to the ground plane which would make the grater cassava come out the side of the drum.

**Pros:**

- One drum is easier to manufacture than two
- Simple frame and containment unit to manufacture
  - Easily accessible materials
- Simple as far as moving components
  - Single planar chain drive
- Easy operation by a human
- Parts that could hurt someone severely are located within the containment unit

**Cons:**

- Manufacturing a drum shaped grater is slightly more difficult than a flat sheet
- Cassava would end up inside the drum and be difficult to evacuate
  - Increased weight of moving assembly
- Drums run the risk of being dented in if not properly produced and reinforced

**Moisture Management**

**Hydraulic Jack**

One possible design incorporates a hydraulic jack that is human powered by using a hand jack. While the jack is operated, it will lower a ram head that will force a push plate down to make contact with the cassava inside a mesh sack. This mesh sack will allow for the cassava to be contained, but still...
allow for adequate water drainage from the raw cassava. Below is an illustration of the design concept with the major and important components labeled.

![Hydraulic jack dewatering concept schematic](image)

**Figure 11 – Hydraulic jack dewatering concept schematic**

**Pros:**

- Easy design to manufacture
- Easy to operate
- Can be operated by one person

**Cons:**

- Requires purchase of expensive components
  - Hydraulic Jack
- Frame would have to be sturdy enough to withstand the force created by the jack
  - Strong/more expensive materials
- Safety hazard because of the amount of force available
  - If not careful something could break and hurt someone
Screw Press

Another possible design is one very closely resembling the above design with the only main change being the threaded rod and handle instead of a hydraulic jack. Like the above design, this device is human operated by having a human turn a handle that when in contact with the support frame will drive a ram head down to force a plate into contact with raw cassava. This force will compress the cassava and force water from the raw cassava. Another change is the storage medium that the cassava is in. In this design the cassava is in a hollow cylinder with a perforated bottom that will allow for water to drain when it is being pressed. Below is an illustration showing the labeled components on the proposed device.

![Figure 12 – Screw press dewatering concept schematic](image)

**Pros:**

- Simple to manufacture
- Can be operated by one person
- Doesn’t require an additional sack for the cassava
**Cons:**

- May be difficult to operate by women and children
  - Large force necessary to turn handle
- Frame would need to be very sturdy
- Drum may want to bow outwards under the pressure created
- Frame would need to be threaded
  - Complicated to produce
  - Would need to be very strong

**Perforated Drum**

This design incorporates a centrifuge type device that will draw the cassava towards the perimeter of the device that will force the water from the cassava by centrifugal force, much less how a washing machine draws water from the clean clothes at the end of the cleaning cycle. Inside this drum will have numerous perforations that will allow the water to drain, but prevent the cassava from leaving the device. To allow for the cassava to travel to the end, an angle would be incorporated that would allow for cassava to exit the drum into a collection bin. Below is an illustration of the conceptual design with important design features and components labeled.

![Perforated rotating drum centrifuge dewatering concept schematic](image)

**Figure 13** – Perforated rotating drum centrifuge dewatering concept schematic
Pros:

- Potential to process cassava continuously
- Process large amounts of cassava

Cons:

- More difficult to manufacture
- Requires great speed to create large enough force for water extraction
- Physically demanding by those operating device

Parallel Press Plates

One final water extraction method involves using two parallel plates that are lowered by the operator using wingnuts on threaded rods that when turned will lower the top plate towards the bottom plate and thus compressing the cassava in the center in the process. This device would see the cassava in a mesh that allows water to escape, but still keeps the cassava contained. Below is a schematic of the proposed device with the important components labeled for clarification.

![Figure 14 – Parallel press plates dewatering concept schematic](image)
Pros:

- Easy to manufacture
- Cheap to manufacture
- Could make several without a lot of penalty thus increasing throughput capability
- Can be operated by one person
- Easy to operate (can be operated by women and children)

Cons:

- Quantity of cassava processed
  - May take a considerable amount of time to drain enough water
- Does not apply a force in the center
  - May bow if not reinforced properly
- Does not in and of itself provide a way to collect water

Tapered Belt Press

The tapered belt press design consists of two belts wrapped around multiple rollers. These rollers will rotate in order to draw the cassava further into the device. As the cassava gets further in the distance between the two belts decreases and squeezes the cassava more and more. By the end of the belt line most of the water will have been squeezed out of the cassava mash. The length of these rollers and thus the belt will be dependent on the amount of cassava that needs to be processed as well as human energy requirements. The rollers would be driven by a chain and gear system connected to pedals.
This design would require a lot of input power if it was going to be able to squish the cassava a sufficient amount. This may or may not be achievable through gearing and human input. Further analysis would be required to determine if a human could be reasonably expected to power this machine on their own.

**Pros:**

- Should be a quick process
  - Allows for increased throughput
- Would be human powered
  - Dependent on some factors

**Cons:**

- Fairly large device
- Belts may be hard to come by
- Complex construction with tight tolerances
- Requires a lot of material because of its large size
- Requires a large power input
May not be obtainable by a human through gearing

Milling
Plate Mill

One method that may be utilized to mill the Cassava is to create a plate mill design. An adaption of the plate mill is the burr mill is seen is to grind coffee or peppercorns, however, it can be adapted to grind cassava into flour. The cassava would be fed through a feed hopper and fall down between two abrasive surfaces. One abrasive surface will be revolving on a shaft and will be powered by a hand crank. A spring and an adjustable knob will be added to the end to allow adjustments to the distance between the abrasive surfaces. The closer the abrasive surfaces are placed together, the finer the cassava may be ground into flour. The second abrasive surface will be attached to the main housing and will remain stationary. As the cassava is ground into small particles, it will be dispensed from the bottom of the mill into a container.

Pros:

- Adjustable knob allows for changes in size of the particle of cassava flour

![Plate mill concept schematic](image)
• A burr grinder creates less friction and requires fewer rpms to accomplish goal.
• Relatively simple assembly.
• Easy to clean
• Suitable for small scale cassava processing
• Can grind both dry and wet materials
• Parts are more available

Cons:

• Nothing but gravity to pull the cassava through mill. If gravity is not effective enough, would require additional forces, such as a revolving screw to push food through.
• Using a hand crank for long periods of time would wear out the operator
  ○ Flywheel could be connected to a pedal system

Rolling Mill

The rolling mill concept would mill the cassava through using cylindrical rollers in opposing pairs. The entire surface area of these drums would have a milling type surface to break up the cassava. For this concept to work, it would require the use of at least two sets of rollers that incrementally reduce the space between the rollers, to the point where it would mill the cassava into particles small enough for flour. The cassava would be fed through a feeder hopper and pulled through the rolling mill by the cylindrical rollers. This would require four rotating shafts, and would be powered by making use of the same bicycle used for grating. The upper cylinders would be pulling in larger volumes of cassava than the lower cylinders would be milling the cassava, and therefore, the upper cylinders would have to be
geared down to reduce the speed at which they turn. The milled cassava would be dispensed at the bottom of the rolling mill through a chute into a container.

Figure 17 – Rolling mill concept schematic

**Pros:**

- Can mill the cassava to a very fine grain.
- Is a self-feeding machine that pulls the cassava through the mill

**Cons:**

- Would require the use of the bicycle used for grating and therefore would allow only one process to be done at a time.
- With four rollers needing to be in motion at the same time, all pulling cassava through, it would be hard work for the operator.
- If the rollers are geared down for easier operation, it means that the milling process would take more time.
- Rollers need to be of strong material so as not to bend inward when cassava is pulled through.
Would be more expensive to fix as materials would not be as readily available.

**Manual Labor**

After the cassava runs through the drying process, it is in a large solid form that must be broken down into flour, and one way to do this is by manually breaking down the chunk of dried cassava by hand. To do this, small pieces are broken off the larger dried brick of cassava and placed into a bowl for crushing, often a depression in a stump of wood. Then, a thick stick or hammer can be used to repeatedly strike the small pieces of cassava, breaking it up until it is in particle form. This is then worked through a fine strainer, so that only particles of cassava of a certain size will pass through. Any cassava pieces that are still too large, are returned to the crushing bowl and continually worked until they are of the appropriate size.

**Pros:**

- Cheapest method
- Very safe as there are basically no moving parts
- Easy to clean
- Replacement tools would be easy to find

**Cons:**

- Very labor intensive and would put strain on women and children doing the work
- Not an efficient way to mill cassava
- Time consuming process
- Only smaller amounts can be worked on at a time

**Hammer Mill**

A popular method for milling in Africa is to utilize a hammer mill and this could be used to mill cassava.

The idea behind a hammer mill is to crush aggregate material into smaller pieces by repeated blows of
little “hammers”. The design would be relatively simple, with a steel drum containing a horizontal rotating shaft on which hammers are mounted. The hammers would be fixed to the rotor in the center. Beater bars would be incorporated into the upper semicircle against which the cassava impacts. The rotor spins inside the drum while cassava would be fed into a feed hopper. The cassava is impacted by the hammer bars and is shattered them, allowing them to fall through the screen surrounding the hammers. Gravity will allow flour to fall in a chamber below the hammer mill. The device would be run by connecting a belt or chain to the shaft and running that to a bicycle frame to make it human powered.

Figure 18 – Hammer mill concept schematic

Pros:

- Works well with moisture content around 12 percent. If Cassava not completely dried, it will not be an issue.
- Drier the crop, the less power required. Five percent less power is needed for every one percent reduction in moisture content.
- Could be adapted to work with bicycle for grater

**Cons:**

- Work best when run at high speeds
- Screen replacements can increase the running cost of the machine
- Multiple moving parts

**Ranking**

Ranking of concepts was done individually for each type of device as they are not comparable with one another. The methods for ranking them; however, are the same. Decision matrices were produced for each of the three device types. The parameters being evaluated within these matrices are the design specifications that have already been established for this project. A list of these design specifications, their importance, and factors affecting them can be seen in the appendices. The decision matrices were also weighted based on the importance of the individual design specifications. To accomplish this, the value assigned to each specification for each concept was multiplied by the value previously assigned to that design parameter. The original design specification was valued on a scale of three to zero, three being the most important. Because the values are being used for weighting purposes, anything with the value of 0 was given a weight of 0.05. This essentially makes those parameters negligible but they were included for completeness. The following three tables display the previously explained factors.
### Table 6 – Grating concept decision matrix

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### Table 7 – Water management concept decision matrix

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Table 8 – Milling concept decision matrix

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FEA Analysis

A lot of smaller mathematical analysis and calculations went into the final prototype designs. This section includes an example of some of that analysis. Finite element analysis was carried out on the shaft on which the grating drum would rotate to determine if the selected stock would deform under the weight of a hopper full of cassava root. Two distributed loads were chosen for this analysis: 34 lbs. and 40 lbs. The results are shown below for each load.

Figure 19 – Max Deflection for 34 lbs.
Figure 20 – Max Stress for 34 lbs.

Figure 21 – Max Deflection for 40 lbs.

Figure 22 – Max Stress for 40 lbs.

Table 9 – Results of Max Deflection and Max Stress for Distributed Loads of 34 lbs. and 40 lbs.

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<th>Load (lbs.)</th>
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<th>Max Stress (psi)</th>
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Final Prototypes

Grater

To assure effective grating of large quantities of cassava root, a bicycle was added to the grater design. This bicycle turns a grating drum with screw heads extruding from the surface as shown in figure 23. This grating surface effectively shreds food. This style grating surface was chosen for its low cost and easy manufacturability. It should also offer a long life. A completed prototype can be seen in figure 24.

Figure 23 – Close up of grating drum
Dewatering

Squeezing the cassava between two parallel plates is the best method for reducing the moisture content of the cassava. This will expel a majority of the water and reduce the sun drying time required. This method is already being used in other regions and proves effective. It is also very cheap and easy to construct. Other more complicated and expensive methods may have seen a greater reduction in the water content but very ultimately determined to not be worth the added expense. The cassava should be in some form of porous bag at this point to assure water can be evacuated. Any evacuated water should be assumed to be unsafe for use in any manner (see table 1). Waste water should be disposed of in a charcoal pit. Pulling the two plates together (applying a force to the bag of cassava) can be done in a number of ways including the suggested threaded rod. Alternate methods include heavy stones or ratchet straps. The force should be maintained until water stops dripping from the cassava bag. Greater water removal at this stage assures that solar drying will reach the desired water content and even has the potential to reduce solar drying times.
Drying

Any table of suitable size depending on desired throughput can be used for sun drying the dewatered cassava. The cassava will dry best if the layer of ground cassava is no more than an inch thick. At this thickness the cassava should only need to be in the sun for 8 hours. Desired moisture content is 12%. It is also recommend that the table has raised edges to both hold the product in and help prevent contamination. Clean polyethylene or tarpaulin sheets should be placed between the table and the cassava. The sheets will both absorb additional sheets and prevent mold and bacterial growth.

Figure 25 – Grated cassava dewatering device design

Figure 26 – Cassava drying table w/polyethylene sheet concept
Milling

A hammer mill was used as the inspiration for the milling machine (figure 27). Post sun drying, the cassava will be put into the milling machine to be ground into a fine powder. Bicycle power was implemented for the milling machine as well. Figure 28 shows that milling plate that is housed within the drum and rotated by the bicycle. Chicken wire mounted to the edge of the milling plate will agitate the powder and force it against the wall of the drum and eventually against the exit sieve shown in figure 29.

Figure 27 – Completed milling machine prototype
Conclusion

Through thorough research a process was determined that would best solve the issue of converting cassava roots into safe cassava flour. Safe meaning cyanide levels within the 10ppm threshold and reduced chance for aflatoxin growth and bacterial contamination. Devices that were developed to best perform the tasks faced in the process were settled upon through iteration and analysis to determine which would best fit the requirements and design parameters. The devices are all
low cost and human powered. Materials used and manufacturing techniques were chosen to reduce the overall cost and allow for easy reproduction in the focus region.

These devices and the accompanying process solve the issue of lost crop from spoilage due to post harvest physiological deterioration by increasing the shelf life from 3 days to 3 – 6 months. Food supply can be increased for small scale farmers which means more food and money. In an area with such a high percentage of malnourished people having more food has a large impact. Farmers will also have the ability to sell excess that may not have previously existed increasing their financial standing. Probability of producing flour with mold or bacterial growth has been reduced which along with the final product having acceptable cyanide levels means the food is safer and healthier to eat. Because of the focus on a universal process development, these benefits can be had by people in all regions.

Diffusion of the innovation should be the focus now. The devices and process should be spread to the people who need them so that they can begin to have a positive impact on their lives. This is one of the most challenging and important stages.
References


