Rural Food Processing
Final Report

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DISCLAIMER

EXECUTIVE SUMMARY

The dish Ekwang features ground cocoyam that is rolled inside of cocoyam – or other types of – leaves. This process is time-consuming and labor intensive as it is currently performed almost entirely by hand. After grinding, it requires individuals to manually dispense cocoyam onto leaves which are taken by hand and slowly wound up tightly where they will then be cooked. The project presented by Isaac Zama, a humanitarian, was to create a device that will reduce the time requirement of the rolling process by allowing for automation of the process through a simple and easily manufacturable design.

Through conversations with the client, mentor, and within the team, the team was able to determine a set of customer and engineering requirements. The most important customer requirements determined were reliability, safety, simplicity, and that the design is faster than the current hand rolling process. The most important engineering requirements determined were factor of safety, cost, and minimizing the time required to produce one roll.

From these requirements, the team determined initial designs. As the semester progressed, conversations with the client assisted in shaping the overall design of the system. The system is composed of two main subassemblies: the dispenser and the roller. The roller is mainly a base with a roller bar that is connected to a handle. The roller bar is fed through two side rails that assist with the direction of motion. Connected to the roller bar and the base is a belt which is also partially forced through a gap towards the end of the roller base. The dispenser began as a custom design that was exchanged in favor of a ready-to-buy product.

The dispensed cocoyam is placed on one end of the roller by the handle. The handle is advanced forward to the opposite end which wraps the belt as it progresses. This motion causes the leaf to roll onto itself as the system is advanced. Once the cocoyam is completely rolled, the positioning of the gap in the base allows for the rolled cocoyam to fall through to prevent unravelling. The handle is then pulled back toward the user and the final rolled product remains in the gap, allowing for removal by the user.

The final design was an iteration of the current plexiglass design and has been created from wood, which is a readily available material in Africa. Wood also offers accessible processes for manufacturing the final product. The team worked on schedule to allow for early progress toward deliverables. The team ultimately plans to deliver the highest quality end product to the client in order to help communities in West and Central Africa.

Table of Contents

Contents

Table of Figures

1 BACKGROUND

Introduction

The project titled "Rural Food Processing" will be designed and created by Team 16 as part of NAU's senior capstone program. The project design includes a simple raw cocoyam dispenser and roller that are both reliable and safe for daily use in the creation of Ekwang meals. The project aims to be a continuation of the manual grinder of cocoyam completed by a different senior capstone team from Georgia Tech last year.

Figure 1 Raw Cocoyam [1]

Raw cocoyam, as shown in its un-grated form in Figure 1, is the base ingredient for Ekwang. The grating of the cocoyam is done prior to the introduction of the processing system. The purpose of this project is to provide an alternative method to substitute the current hand-rolling technique used for rolling processed raw cocoyam in leaves by members of West and Central African communities. The current hand-rolling method is time consuming and requires effort as it is a process done entirely by hand. The cocoyam dispenser and roller will provide a better alternative that is both quicker and less demanding overall. This will benefit both residents of the rural areas of Africa as well as those living in cities in Central Africa. This project will also aid in the transfer of this technology to the younger generation in African rural areas, which will help in the creation, sale and spreading of the technology among the members of the community. This will aid the Central African communities by providing a simpler solution in the long-term than the current highly inefficient and demanding method of hand-rolling the cocoyam in leaves.

Project Description

The following is the original project description provided by the sponsor:

"Grated raw cocoyam, called Ekwang and Kwacoco Bible are staple meals in much of West and Central Africa. Traditionally, this food is prepared by manually grating cocoyam and wrapped in vegetable or banana leave. The process is labor intensive and time consuming. It can take up to 2 hours to grate cocoyam's for a family of five. A few rich people in the cities in Africa and the diaspora have found creative ways to still eat the food by using blenders or juicers to process the food. However, mothers in rural areas still use the traditional manual method of grating the cocoyam's and wrapping it in leaves. Preparing the food takes enormous amounts of time from women in performing other productive activities. There is a need to improve upon the process of preparing the food by designing a simple and affordable system to use to process the food. Such a system will not only help those in the villages with no electricity, but also people in the cities that have roadside restaurant that sell the food. Even the rich people in the cities will still like to use it, since it reduces their electricity consumption from using the blender to make the food. Africans in the diaspora have figured out a way to use aluminum foil to wrap the paste since it is difficult to have leaves here.

2 REQUIREMENTS

The Rural Food Processing capstone project for the 2019-2020 academic year includes creating a roller and dispenser system that prepares the dish Ekwang faster than the current, traditional method. The client is mostly interested in the design package so that the design can be replicated in Africa by local craftsmen. There were no major changes to the requirements last semester, but small adjustments were made and are highlighted in this memo, along with Testing Procedures the team will follow in order to prove the requirements.

Customer Requirements (CRs)

Table 1 Customer Requirements and Ranking

Customer Requirements / Importance	Importance Ranking
1. realibilty	3
2. durability	2
3. lightweight	1
4. safe to use	3
5. simplicity	3
6. low cost	2
7. Easy to use by anoyne	2
8. mobility	1
9. faster than hand rolling	3

The customer requirements for this project originate from Isaac Zama, who is a humanitarian rather than an engineer. Because he is not an engineer, he had a different outlook on the project which contributed greatly to the project. Current Customer Requirements include reliability, durability, lightweight, safe to use, simplicity, low cost, easy to use by anyone, mobility, and faster than hand rolling. Between the Preliminary Report and now, the only changes to the CRs is that “adjustable dispensing” was removed and “easy to use by anyone” was added. This was based on feedback from the client. The client’s original intent for adjustable dispensing was discarded in favor of a system that is more standardized with every use. The easy to use by anyone requirement was added after discussions with the client and his emphasis that the design is intended to be used with a wide range of ages and individuals of different backgrounds as well as purpose for the machine (at home use vs. commercial use).

The customer requirement ranking was based on what the customer wants. The scale of the customer requirement is 1-3, where 3 is the most important requirement. The importance rankings can be seen in Table 1 above. The top customer requirement requirements are reliability, simplicity, faster than hand rolling, and safe to use. The device needs to have high reliability in order to ensure that the workers will be able to produce a roll with every pass through the system. Moreover, the device needs to be simple to use because people in a rural village will be the main operators. Additionally, the device will be manufactured in these communities which have limited resources and tools. Therefore, simplifying the device is the only way to ensure its public utility. The device must also be safe to use for everyone in the community since both children and adults will use the system.

Requirements based on what the customer stated as important but not of the highest consideration have a lower weight in the requirements in Table 1. These include durability, low cost, and easy to use by anyone. The device durability and cost were not as important to the customer as the device will be manufactured with different materials in Africa than what the final design may be created with. Consequently, the durability and low cost will be ultimately determined by the workers in Africa. However, if our design was able to account for the materials and costs of manufacturing in Africa, it would be better for the customer. The ease of use by anyone is a highly important requirement since it should be used by anyone from the community and it should be understood simply. The lowest requirements were based on what the customer deemed as features he would like incorporated. The client would like the device to be lightweight or mobile. The customer explained that the device will be used in almost stationary places such as homes, street. However, the customer says that it would be better if it can be mobile to ensure that it does not get stolen, especially if the device was being used in the street.

Engineering Requirements

Table 2 HOQ Engineering Requirements

	Customer Requirement/importance	Importance Ranking	Engineering Requirement	low weight	base footprint	smooth edges	minimize time to produce one roll	low price	Low center of gravity	Factor of safety
Target ER values				7 kg	0.5 m^2	5mm	20 sec	$35.00	-	3
Tolerances of Ers				>10 kg	>0.625 m^2	>2.5	>45 sec	>$45.00	-	<3
Testing Procedure (TP#)				5	5	5	1	5	3	5

ER #1: Low Weight

ER #1: Low Weight Target = 7kg

The target for this requirement was determined based on the client's intent of the device being easy to carry for even children in a village. The team thought of what a realistic weight maximum would be given the anticipated size of the design and what is realistic for a child of around ten years old would easily be able to carry.

ER #1: Low Weight Tolerance = Less than 10kg

The team determined that the requirement necessitated a strictly "less than" tolerance because the goal is to keep the weight as low as possible. By providing a 3kg buffer above the target weight, this allowed for changes in materials to the design, if certain components were deemed to need to be made out of heavier, more durable materials.

ER #2: (changed from fall) Base Footprint

ER #2: Base Footprint - Target = 0.5m²

The target value of this requirement was determined based on the client's desire for mobility. The team interpreted mobility to translate to a small device, which also reduces weight as a result. The team originally anticipated only needing a target value of $0.125m^2$, but this proved to be too small for the project once a demonstration was held and the prototypes were created

ER #2: Base Footprint - Tolerance = less than $0.625m^2$

The team determined the tolerance should be a strictly less than relationship because the smallest possible design is ideal in order to meet the CR of mobility and low weight.

ER #3: Low Price

ER #3: Low Price - Target = $35.00

The team took the upper end of the target price of the design by the client and determined that this target price would be ideal to achieve or even stay under for the final product.

ER #3: Low Price - Tolerance = Less than $45.00

$45.00 was the target dollar amount set by the client for the device. The team determined success can be determined in this requirement by staying under the amount set by the client.

ER #4: (changed from fall) Minimize time to produce one roll

ER #4: Minimize time to produce one roll - Target = 20 seconds

The team determined based on research and demonstration that the entire process for dispensing and rolling one Ekwang would be reduced to 30 seconds or less in order to be faster than the hand rolling process. If it can consistently roll to this target, it will also prove the system's reliability.

ER #4: Minimize time to produce one roll - Tolerance = Less than 45 seconds

The team originally had a tolerance set to less than 60 seconds, but it was determined that this should be lowered to ensure that the final design has a more significant impact on the time for the process.

ER #5: Factor of Safety

ER #5: Factor of Safety - Target = 3

One of the customer requirements for the project is that the system is safe to use because of the variability in the age and skill of those operating the device. The team determined a factor of safety of 3 is reasonable for the system because it does not involve sharp parts nor parts that will operate independently of the operator's direct, manual input.

ER #5: Factor of Safety - Tolerance = Greater than 3

The team determined that the factor of safety should be only greater than 3 and not less because of the safety requirement. A factor of safety approaching 1 or less than 1 would create potential hazards to the user and/or a decrease in the reliability and durability of the design.

ER #6: (changed from fall) Smooth Edges

ER #6: Smooth Edges - Target = Radius = 5mm

The customer requirement for safety drove this requirement. The team determined that one way to ensure safety is to prevent injury. This was interpreted in one way as preventing injury in the form of cuts, which the requirement is designed to accomplish.

ER #6: Smooth Edges - Tolerance = +/- 2.5mm radius

The team determined that edges within a +/- 2.5mm radius is more reasonable of a tolerance than the original tolerance set during the fall. If edges are more rounded than this, that would also be acceptable, but the team would ideally remain in this range to ensure material is not unnecessarily wasted trying to achieve overly rounded edges.

ER #7: Low Center of Gravity

ER #7: Low Center of Gravity – Target = z-direction height in lower 1/3 total height at rest

The customer requirement for reliability helped to drive this requirement. The team interpreted this through having a stable device, which can be partially achieved through a low center of gravity. The target was determined by determining a reasonable z-direction value, as the x-direction and y-direction should be centered due to the symmetry of the device.

ER #7: Low Center of Gravity - Target = z-direction height in lower 1/2 total height at rest

The team determined that as long as the center of gravity is located in the lower half of the design, this would be acceptable to meeting the requirement, although lower than this is desired.

House of Quality

Table 3 HOQ Rankings

Customer Requirement/importance	Importance Ranking	Engineering Requirement	low weight	base footprint	smooth edges	low price	minimize time to produce one roll	Low center of gravity	Factor of safety
1. realibilty	3		1	0	0	3	9	3	9
2. durability	2		3	0	3	3	1	1	9
3. lightweight	1		9	1	0	3	0	0	0
4. safe to use	3		0	0	9	0	0	1	9
5. simplicity	3		1	1	0	9	0	0	0
6. low cost	2		9	3	0	9	0	0	3
7. Easy to use by anoyne	2		1	0	0	3	1	3	0
8. mobility	1		9	9	1	0	0	1	0
9. faster than hand rolling	3		0	0	0	0	9	0	0
Absolute Technical Importance (ATI)			50	19	34	69	58	21	78
Relative Technical Importance (RTI)			11.8	5.8	10.3	21.0	17.6	6.4	23.7
Target ER values			7 kg	0.5 m^2	r=5 mm	$35.00	20 sec	-	3
Tolerances of Ers			>10 kg	>0.625 m^2	<5mm	>$45.00	>45 sec	-	<3
Testing Procedure (TP#)			5	5	1	5	2	4	5

Low center of gravity targets reliability. Quantifying center of gravity is important to determine whether our design will be reliability. The target goal is to have low center of gravity via solid works to know the actual center of gravity. Then experimental drop and force tests will be applied to find the experimental center of gravity. These tests will ensure that the design is reliable.

Factor of safety targets to quantify the types of fastener that will work on our design without breaking. The target goal is having the factor of safety equal to 3 and a tolerance greater than 3. This factor of safety will ensure that the fastener will not be lose or break due tensile stress.

Low price targets how the price is affected by other customer requirements. The price is mostly affected by simplicity because the simpler the design will lower the manufacturing cost.

The price goal is $35, and the tolerance is to be less than $45. The goal is set to $35 because the lower the price the better. The price goal is lower than our customer price goal because the lower price, the more people will be able to afford the device.

Low weight targets to quantify the mobility of the device. As the weight decreases, the mobility of the device will increase. The goal is to create a design of approximately 7 kg. This weight was determined based on assuming that this device will be carried by kids and adults. Therefore, 7 kg was based on the average weight the team determined would be easy enough for a ten-year-old to carry. The tolerance is set to be less than 10 kg as the upper weight limit.

Minimize time to produce one roll targets to quantify the time it will take to create one roll when compared to the hand rolling process. The goal determined prior to a real-life demonstration was 30 seconds. Material strength's target is to quantify how durable the material is. The goal is to have a strength of 44 MPa. The 44 MPa will ensure that our design is capable of handling high forces. The tolerance is set greater than 44 MPa because the higher the material strength the better volume of material to create device target is to quantify how mobile our device is. Since the materials to be used have not been determined, this may shift.

Smooth edges targets to quantify the safety of the device. The goal radius of the design is to have a radius of 5 mm. The team predicts this radius on sharp corners will provide a smoot finish to minimize the danger of cuts on the device. The tolerance is set to greater than 5 mm because as the radius increases, the curvature becomes smoother. Base footprint targets to quantify how much space the device will occupy. The goal 0.125 m^2. The team deemed this reasonable considering it is a two-stage system but anticipates a vertical orientation for the device rather than horizontal. The tolerance is set to more than 0.25 m^2 because the larger the design, the less mobile the device becomes.

3 Functional Decomposition

The goal of the rural food processor is to receive the cocoyam, dispense the cocoyam, and then roll the cocoyam in order to form the proper traditional dish. A black box model was created to show the overall process of turning the cocoyam into the rolled dish through the device. The functional decomposition shows a detailed overview of how the device will achieve the task.

Black Box Model

The black box model presents an input material (bolded solid line), energy (solid line), and signal (dotted line) on the left-hand side. These point to the box which represents the device that is being created to perform the task specified within the box. There is then an output material, energy, and signal which defines the end of the process.

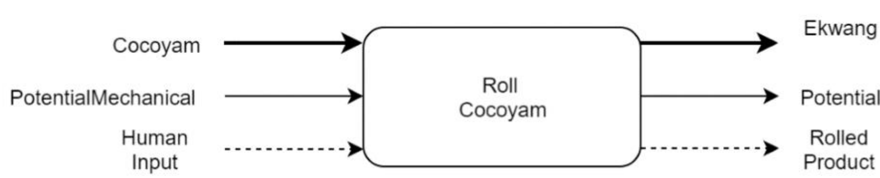


Figure 2 System Black Box Model

Figure 2 represents the overall device inputs and outputs that the team decided were important to the process. However, in contemplating the processes that the system will undergo, the team decided to create a black box for each of the specific actions that the system is comprised of.

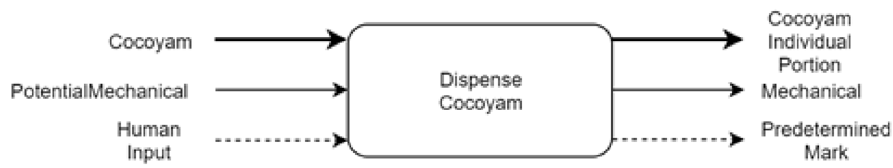


Figure 3 Dispenser Black Box Model

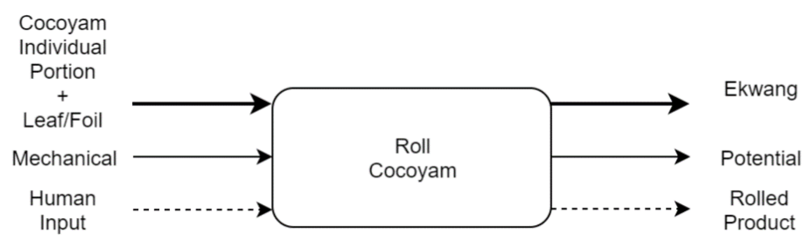


Figure 4 Roller Black Box Model

In the black box models above in Figures 3 and 4, the dispensing of the cocoyam and the rolling of the cocoyam into the final product are split into two distinct black box models. The dispensing process is directly linked to the rolling process because the outputs of dispensing are the direct inputs of the rolling, with the exception of the output signal of the dispensing and input signal for the rolling. By creating these models, the team was more easily able to work towards creating the functional decomposition for the entire system.

Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The team determined that a functional diagram for the project represented in two stages to represent the two subsystems would be the easiest way to define the processes. Moving forward, this decision also drove the team decision to run through concept generation and concept evaluation twice, one for each subsystem, since the final product would be easily combined into the final system.

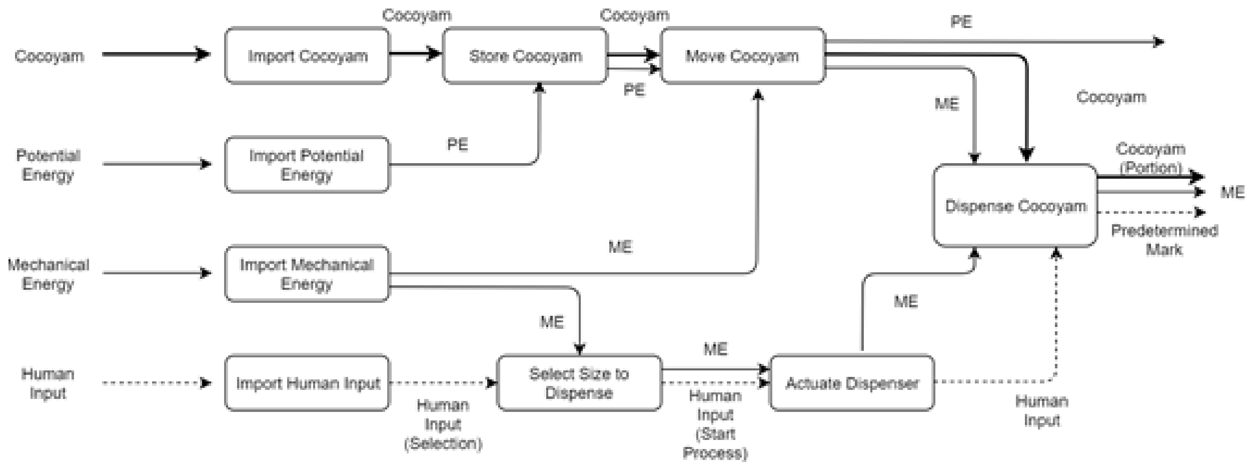


Figure 5: Dispenser Functional Decomposition

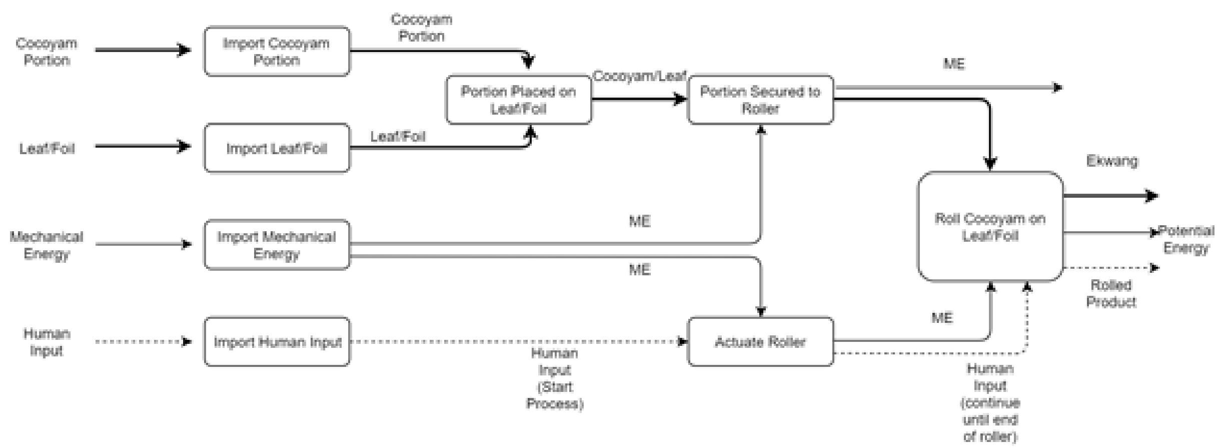


Figure 6: Roller Functional Decomposition

Like in the black box model, the two functional decompositions in Figures 5 and 6 interface as the output of the roller is the input of the roller. The exception is a leaf to house the cocoyam is introduced to the system at the rolling stage, and the initiation for the system is human input with will be the decision to begin rolling by the individual operating the machine.

This model assisted the team in defining where the focus will be in concept generation. By having two distinct subsystems within the project, the team made the decision to complete concept generation and evaluation twice, once for each subsystem. This would allow for the best idea of each to be selected without having too many variants between the systems. The team established that the interfacing of the systems would not be a major concern since the required interface is a direct dispensing of the cocoyam from the dispenser to the roller. By having this established, the team proceeded to generate concepts based on these functional decompositions for each of the subsystems.

4 CONCEPT GENERATION

Full System Concepts

These concepts encompass the three main subsystems defined in the system.

4..1 Full System Design #1: Conveyor Belt

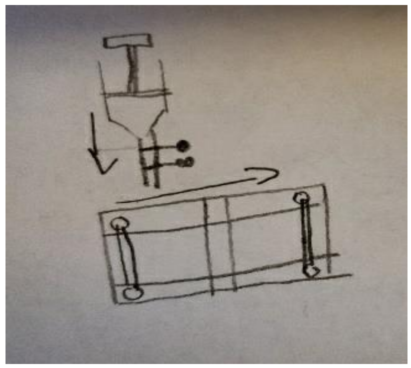


Figure 7: Full System Design 1

This full system design closely represents the final design chosen by the team. This design uses a flat plate with a revolving belt to tightly role the Cocoyam into the banana leaves. A sliding roller handle is mounted above the plate to begin the initial fold and push the semi-completed role forward. Before the cocoyam is rolled it is dispensed from a hopper directly approve straight onto the leaf. Some of the cons to this design are the complexity of parts, limited width to place leaf, and that this device would not be inherently easy to use. The pros to this device consisted of the durability of the design, repeatable roll size, and easily mounted to any surface.

4..2 Full System Design #2: C-Shaped Plow Roller

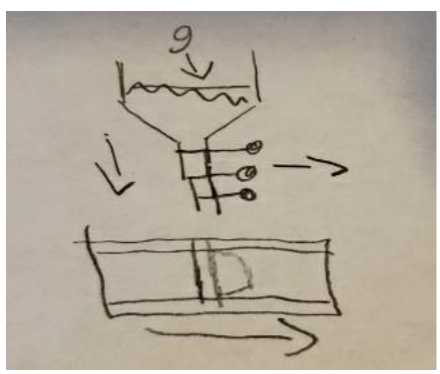


Figure 8: Full System Design 2

This design is a full system representation of a plow shaped roller system. This design uses a set of gates at the bottom of the hopper that can be moved into different positions to easily measure out the desired amount of cocoyam. The larger hopper above will hold the cocoyam which will then be pushed down in the hopper with a plunger. Mounted to the handled will be a “c” shaped plow that will force the leaf to fold onto itself. The cons to this system are the lack of durability in the measuring device high center of gravity with a large hopper, and difficulty in getting the c shape correct. The pros greatly outweighed the cons with a quickly adjustable dispenser, faster dispensing from the hopper, simple to build, and improved time to roll the cocoyam.

4..3 Full System Design #3: Screw Dispenser

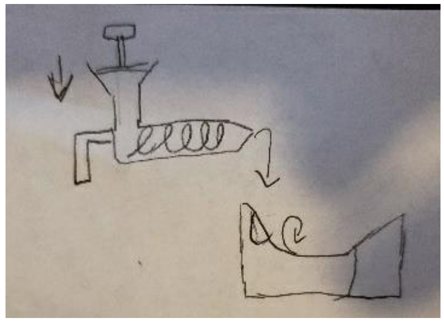


Figure 9: Full System Design 3

This design uses a screw to move the grated cocoyam out of a hopper and onto a covered platform. After the paste has reached the leaf on the platform the user would simply fold one edge and push it down the slope. This is a robust but complicated design, the cons are the complexity of the screw, the design utilizes a small hopper, and does not have a way to measure the amount being dispensed. The pros of the system consisted of being able to dispense as much as the user wanted, high durability, and how easily it could be used by anyone.

Subsystem Concepts

4..1 Subsystem #1: Dispenser System

The dispensing system is defined as the part of the system where the cocoyam travels until it is portioned into the proper amount for each roll.

4..1.1 Design #1: Multiple Flow Gate Dispenser

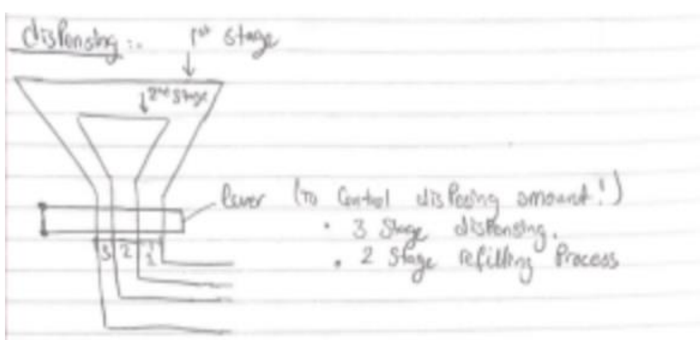


Figure 10: Multiple Flow Gate Dispenser

Quickly measuring multiple volumes is the highlight of this design. This design uses a sliding gate to allow for different size flows to be utilized. The design measure quickly and is robust but struggles in accuracy and controllability.

4..1.2 Design #2: Two Flow Gate Dispenser

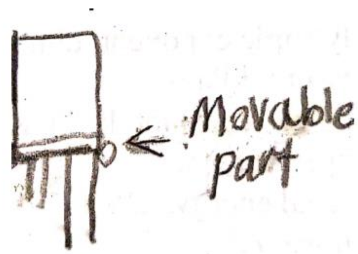


Figure 11 Two Flow Gate Dispenser

This design also features a sliding gate. For this design as the gate is moved the user can chose one of two tube with the flow they desire. This allows for them to easily adjust how much they want dispensed. The downside to a device like this is the inability for the user to premeasure a given amount along with there only being two options for flow instead of many.

4..1.3 Design #3: Screw Dispenser

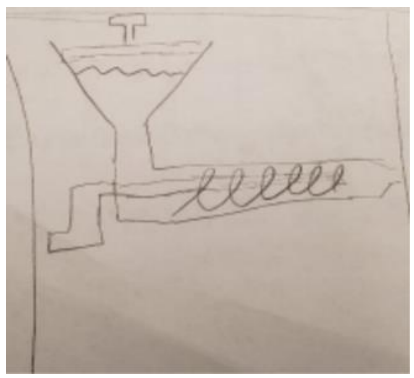


Figure 12: Screw Dispenser

This design gathers inspiration from an injection molding machine by using a screw to push the grated cocoyam forward. The screw dispenser would allow for a continuous stream of material while the user turn the handle. The downside to this is that there would be no way to pre-measure the amount of material being dispensed. The design is robust and easy to learn how to use but lacks in mechanical ability

4..2 Subsystem #2: Rolling System

The rolling system is the system that encompasses the entire rolling process from the end of dispensing to the final product.

4..2.1 Design #1: Preformed Contour

Figure 13: Preformed Contour

This design utilizes a silicon sheet and preformed contour system to roll the cocoyam. After dispensing the paste onto the leaf, the leaf will be pushed down one side of the contour causing it to roll onto itself. The cons are the inability to reliably wrap the cocoyam, the need for a preformed mold, and how hard it would be to teach the technique to the user. The pros are the use of readily available materials, simple to build, and can be adapted to form different sizes rolls.

4..2.2 Design #2: C-Shaped Roller

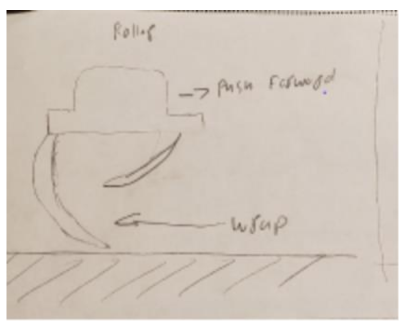


Figure 14: C-Shaped Roller

The roller concept pictured uses two c shaped fins to roll the leaf. As the handle is pushed forward the lowest c will push the leaf up forcing it to follow the curve until the leaf intersects with the second c causing it to roll onto itself. The cons for this design consist of being able shape the fins just right and being able to manage the proper amount of friction. The pros are the ability to easily wrap the cocoyam and ease of use for beginners.

4..2.3 Design #3: First Roll Divot Base

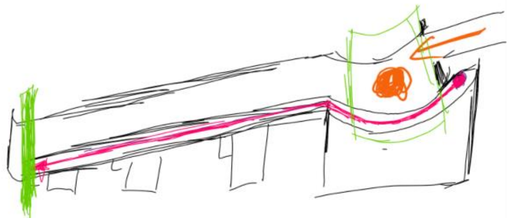


Figure 15: First Roll Divot Base

Using a small divot were a leaf and cocoyam can be staged allows the user to simply fold the leaf over and create the first roll. This allows for quick rolling but causes issues being able to learn how to use the device along with the time to produce one roll not being improved upon compared to hand rolling. These cons are offset by the simplicity and durability of the design.

4..3 Subsystem #3: Reservoir/Hopper System

The reservoir/hopper system is a subsystem that will contain the cocoyam prior to being dispensed.

4..3.1 Design #1: Pivot Hopper System

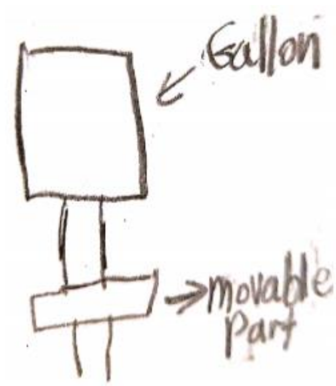


Figure 16: Pivot Hopper System

The Pivot Hopper features a large storage hopper that can be easily filled from the top. With a large hopper the customer will not need to refill as often. To get the material out of the hopper a pivoting fin system will be used to dispense the cocoyam. This system features a large hopper that offer longer uses but has a complicated system to dispense the cocoyam. The fin system would be hard to create and perfect making this design less possible.

4..3.2 Design #2: Descriptive Title

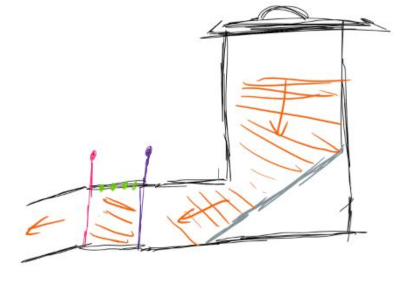


Figure 17: Gravity Fed Hopper

This hopper system uses gravity to push the cocoyam down the slope into the measuring gates. This design is incredibly simple but has some possible issues when feeding the cocoyam. Cocoyam in rather viscous depending on what recipe is being used. With a high viscosity the cocoyam may not feed evenly and consistently into the measuring gates. Causing mismeasurements and increased times.

4..3.3 Design #3: Plunger Hopper System

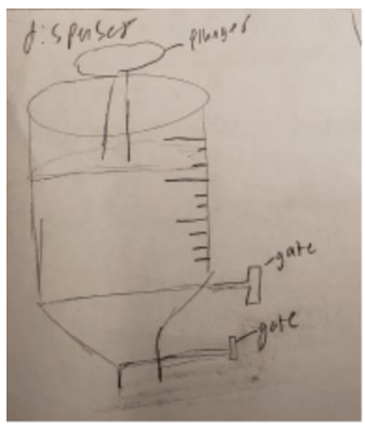


Figure 18: Plunger Hopper System

This design combines the best features of other designs to more accurately meet the customer requirements. Design 1 relied on gravity which could cause issues, so this design implements a plunger to push the material down into the gate system. With the hates in place the customer can measure out the amount of cocoyam or the can remove the gates and use the plunger to supply as much as they desire. The one downside to this design is the possibility of breaking the gates and the small size of the hopper.

5 DESIGN SPACE RESEARCH

This section includes literature review from team research regarding different aspects of the project, benchmarking based on the original system and other devices that are similar to the goal of the system, and a black box model and functional decomposition to describe the goal of the new system.

Literature Review

Each member of the team researched a particular aspect of the project. Findings from this research are outlined in this section.

5..1 Student 1 (Humoud Alanjari)

An important part of the project is to transfer the technology and knowledge for the people to create the design with the materials that they have. Central Africa has the second Largest tropical forest which makes wood a great resource [2].

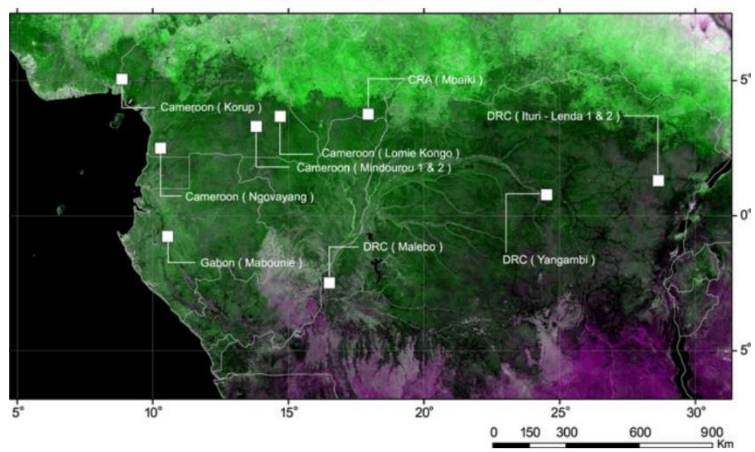


Figure 19: Image of Forest in Central Africa [3]

Figure 5 illustrates a picture of the forests in central Africa [3]. Moreover, the research indicates that Large trees play an important part in indicating the above ground biomass from the large tress. Therefore, the plant life should not include large tress just because of their size. In addition, the forest maintains high densities of large mammals. Therefore, whatever material the team should take impacts into account.

The forest is not the only resource. Africa is rich in minerals such as gold, diamond and iron. However, iron prices are increasing with high demand of iron coming from China [4]. Therefore, the team has to look for alternative to ensure that the design price would not double in the future [4]. If the team decides to go with a metal part, they have to account to the rusting factor. Even though, our client indicated that they use palm oil to prevent iron rusting. The team has to account for bacteria as they can be a source for rusting [5]. Additionally, painting can prevent the iron from rusting which will reduce the maintenance cost for the device [5]. On the other hand, wood has different types that can be used differently in our project. For example, some Umbila wood is durable, resistance to insects and can work easily with both hands and machine tools [6]. On the other hand, Pau Ferro wood dries slowly is resistant to nails. Therefore, Pau Ferro could used as the rolling plane because the rolling plane needs to be smooth and wet.

5..2 Student 2 (Musab Albalool)

First literature review: - Rolling Machine

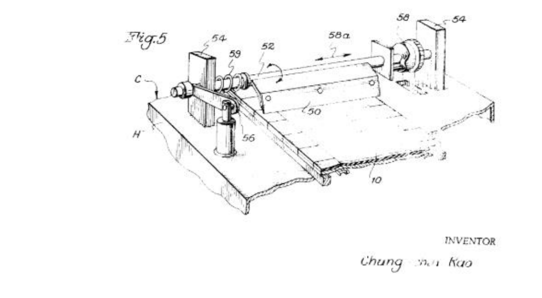


Figure 20: Rolling Machine [7]

In this literature review it discusses the rolling process of the machine. In which the machine is mounted to a horizontal stainless-steel plate and three different pads connected vertically. The pads and the plates are being connected to a large belt to ease the rolling motion of the machine [7].

Firstly, this literature review helped us to come up first with the idea of including a rolling belt on our device, and that's because regardless of any type of material we think we will be using the belt on our device would help us increase the speed of the rolling process.

Second Literature review: A Dehydration Avoidance Mechanism: Leaf Rolling

In this literature review it discusses how plants fold their leaves when their exposed to high temperatures. Plant can benefit from rolling their leaves in two different ways. Firstly, damage caused by the increased leaf temperature resulting from high levels of solar radiation and secondly transpiration rates can be reduced through the creation of a microclimate having both higher humidity and boundary layer resistance near the leaf surfaces [8].

Our project includes different types of leaves for the cooking process, such as banana leaves, cocoyam leaves and collard green leaves. This article helps in knowing more about how plant leaves change during different seasons across the year, by knowing how and when the leaves roll up during the season. Knowing that the leaves roll up due to different temperature change and due to certain damages that the weather caused them to do this we could then assume that we are most certain that the leaf is not good for peeling and using for cooking. We could see if the leaves are not rolled up this could be the perfect season and time to peel off the leaves and use them for the Ekwang and the Kwacoco Bible.

Third Literature review: The influence of roll speed on the rolling of metal plates

In this literature review it discusses how the speed of the rolling can be affected by the type of metal that is being rolled upon. This articles also discusses that the rolling process is divided into different categories based on the metal flow induced and the geometry of the rolled product, as well as it discusses on how the temperature of the plate were using if its hot or cold plate and how will it affect the rolling process and how will the friction play its part in that process [9].

The speed of rolling is one of our main customer requirements is that to build a process that is faster than the hand rolling process that's currently being used. Looking up articles that explains the different speed of roll caused by different metal plates will definitely hit our main target in choosing the type of metal plate for our rolling device, cause as we know different types of metal can cause different friction caused on the banana leave and can cause to slower or faster rolling process.

Fourth literature review: Effects of surface roughness on rolling friction

In this literature review it discusses how that rolling on a horizontal surface will come to rest due to the result of the rolling friction. The rolling friction will eventually depend on two different factors, firstly, the deformation of the object and secondly the deformation of the surface if the surface is soft or thick. In this literature review also discusses the loss of energy due to the elastic deformation. Elastic deformation will depend of the surface of the metal if the surface was real and inelastic then the deformation will result in no loss of energy [10].

The effect of surface roughness on the rolling will help us as a team to come up with different idea on how to look for smooth material surfaces so that we can have energy in our system, and that's because smooth surfaces will result in less deformation of the system as well as we could decrease the loss of energy in our system and by that we have maximum efficiency of our product.

Fifth Literature review: Rolling Process

In this literature review it discusses different type of rolling process. Rolling processes could be preformed under different circumstances such as hot temperature or cold temperature. In the article it discusses how hot temperature will affects the surface of the metal in which it will cause the surface of the metal will deform easily and faster than rolling in cold temperature [11].

The effect of temperature is huge factor in our project since it is based in center African countries. These countries are usually known for very high temperature in which it will affect the surface material and it will cause the materials to deform easily.

5..3 Student 3 (Nygel des Vignes)

The technical aspects focused on were ways or nozzles to dispense the cocoyam paste. Cocoyam is very viscus so it will not flow through a typical fitting like water does, to mitigate flow issues I researched different types of fittings and flow characteristics. The first fitting utilized different volumetric areas and shapes to manage the flow rate of the substance [12].

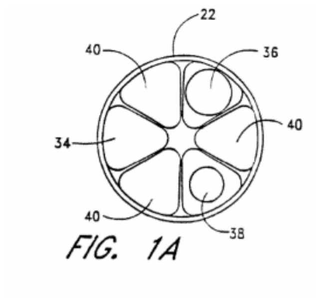


Figure 21: Volumetric Dispenser [12]

This fitting would be easy to purchase and implement into the design. But doesn't not allow for the team to choose the amount being dispensed. Another option that was researched was a nozzle that could change dimension [13]. This nozzle uses the pressure of the surrounding fluid to restrict the flow. So as the tank lowers in volume the nozzle will expand to compensate for the reduced weight of the fluid. The issue of viscous flow was also talked about with the team's capstone advisor Chuck. Chuck mentioned how it would be hard to accurately represent the flow in a simulation or calculation since there were so many unknowns. He stated that the team could make assumptions and hope they would be correct but making the wrong assumption would drastically change the results [14]. Another way to deal with this was to add a plunger or to be able to increase the forces on the substance forcing it through the nozzle. With this in mind the team then need see if it was possible to evaluate the flow at the nozzle and what characteristic the flow would have. To evaluate this research was done on compressible flows. The Journal of Applied Mechanics talked about this and how compressible flow theory would be the most applicable to evaluate the flow at the nozzle exit [15]. Considering a nozzle and compressible flow a system that could handle both seemed to be the best for this product. A pump nozzle was then found which would meet both criteria. The nozzle uses a squeeze bag to propel the material inside the bag out of the nozzle [16]. This is very similar to the plunger idea our advisor suggested. Being able to secure for the design would help to quickly dispense the cocoyam paste.

5..4 Student 4 (Samantha Morrison)

In using various materials, the consideration of a material's contact with food is a major concern to maintain food safety within a system. If a metal were to be selected, stainless steel is one of the main materials for consideration by the team. Stainless steel, and many other materials, have inherent surface roughness. In consideration with stainless steel contact with food particles, this roughness creates cavities that allow for the "attachment and confinement of pathogens" [17]. These pathogens lead to food-borne illnesses due to the repetitive contact with the contaminated surface. In order to avoid this, a use of a foodsafe oil-based slippery coating (FOSC) can be used to block microbial growth, enhance surface cleanability [17]. This article emphasizes how sanitation methods and cleaning habits of equipment plays a large role in preventing the buildup of bacteria. The article mentions how even chemical disinfectants can even be ineffective due to the microstructured grooves [17].

Biofilm formation in particular describes what is trying to be avoided by using FOSCs. A biofilm is of particular concern of increasing post-processing contamination [18]. Depending on the food type that is in contact with the surface, various pathogenic microorganisms can grow on those surfaces [18]. In this project, safety is a requirement, which extends to the safety of the food being prepared. With the knowledge of this article, the team has background knowledge that can drive conversations with the client to determine steps that will be necessary to maintain food safety if metal is the selected material.

Another material of consideration is plastics. Although the cocoyam will not be stored in the system for a prolonged period of time, "Safe Food Packaging and Storage for Better Health and Environment" provides insight into what aspects of the use of plastic are concerning when in contact with food. It is not all plastics that are potentially dangerous; plastics can contain small molecules that, when in contact with food, can transfer to the food in contact with it [19]. The most common compound in question in plastics are xenoestrogens (or endocrine disruptors) which can cause low fertility, insulin resistance, and thyroid dysfunction among other side effects [19]. The transfer of endocrine disruptors is accelerated by the warming of plastic causing a softening in the plastic, as well as the food being a liquid rather than a solid or being acidic [19]. Luckily for this project, the likelihood of endocrine disruptors is lowered because the system will not experience any heating processes when in use, other than heat caused by friction within the system. Although not likely a large concern, the team knows to investigate plastics before use to ensure that it is food-grade in order to avoid the health problems outlined within this article.

With the use of plastics, another potential option to reduce costs is the use of recycled material. This would help to minimize adverse environmental impacts of plastic waste. Monomers are the driving force behind the composition and chemical nature of plastics, but there are hundreds of plastic structures that can be created using various polymers [20]. As described previously, there is an allowance for transfer through plastics – although this article focuses on the permeation of gas and vapors – and that barriers are necessary when dealing with thin plastics such as wrappers [20]. The use of recycled material increases the chance of additional chemicals present in the material than "virgin material" because remnants of a container's previous contents can be within the chemical structure of the recovered plastic [20]. Although recycled plastic is an opportunity for West and Central African communities to reuse materials, the team will have to consider the possible effects these materials can have when used in the system. The team will have to evaluate the best ways to maintain food safety so, if materials like these are used, the community is aware of potential dangers and how to potentially eliminate these risks.

Another concern for food safety is the handling of the equipment and the food being prepared. The client mentioned that the system is intended to be used by both families as well as street vendors. When observing vendors at random in New York, many vendors do not follow proper health codes which can lead to contamination of products [21]. Although New York has different standards than West and Central Africa, a consideration of the handling of the food prior to being inserted and after it has exited should be mentioned within the operation instructions of the system.

Benchmarking

The rural food processing project is based entirely on improving upon the pre-existing system for dispensing and rolling cocoyam in order to create traditional West and Central African dishes. The team had the opportunity to meet with Jacky Nwana who was a native currently residing in Arizona. She gave a demonstration of the process of preparing the dish. During this time, the team was able to observe the overall preparation steps in order to collect data on what subsystems the system could be broken up into in order to achieve the goal of reducing the preparation time. From these observations, the team determined that the dispensing the cocoyam and the rolling of the cocoyam were really the only subsystems present and that these two actions were where the time reduction for the overall process can be maximized.

5..1 System Level Benchmarking

The overall existing design for the system is the traditional method of preparation as presented by Jacky Nwana. This was the only system that really reflected the subprocesses together in a cohesive system. As such, the team decided to research other native's preparation methods in benchmarking to discover any details that may differ between the traditional methods,

5..1.1 Existing Design #1: Jacky Nwana's Method

This design was our physical observation of the process as demonstrated in Phoenix by Jacky Nwana [22]. She started the process with raw ingredients and continued through beginning the cooking process. Based on conversations with our client, the team was able to specifically pinpoint the time in the process where the device should fit. This was identified as when Nwana began scooping the prepared cocoyam into a leaf and then rolled it by hand. After this, the prepared portion was placed into a pot for cooking, but the client identified this transferal of the product was not necessary in the design.

This system meets many of the requirements because it is the baseline design for the creation of the new system that will introduce an ease of use and automation of the cocoyam rolling process. The requirement is does not meet is being faster than the current method, due to the fact that it is the same method.

5..1.2 Existing Design #2: Ekwang – Precious Kitchen

Another system design is the Ekwang prepared by Precious Kitchen [23]. Her recipe for the cocoyam differs in contents compared to Jacky Nwana's recipe. Her technique varies slightly from the demonstration that the team was able to watch. Instead of rolling the entire roll from the center evenly, she rolls the cocoyam from one side to the other, starting on the left and moving towards the right. When the initial roll is complete, she loosely wraps the remaining amount and places the roll directly into the pan. This method also meets the requirements of the project except for being faster than the current method, because it is another iteration of the same method.

5..1.3 Existing Design #3: Kwacoco Bible – Precious Kitchen

Kwacoco Bible is prepared in a different way from Ekwang, but also contains a cocoyam mixture wrapped inside of a banana leaf [24]. As opposed from a small roll, the amount of cocoyam placed inside of, the Kwacoco Bible dish is three times, if not more, the amount of cocoyam used in Ekwang. Additionally, the technique used in this system is a centered start of a roll, much like Jacky Nwana's method, and then the roll is loosely continued until the entire banana leaf is used. At the end, the ends are then folded under the roll, something unique between the Ekwang and Kwacoco Bible dishes. This method also meets the requirements of the project except for being faster than the current method, because it is another iteration of the same method.

5..2 Subsystem Level Benchmarking

The subsystems identified in the system include a dispensing mechanism, a rolling mechanism, and a reservoir. These subsystems were used to identify benchmarking designs.

5..2.1 Subsystem #1: Dispensing Mechanism

In this distinct subsystem, cocoyam is inserted into the device. It is then moved through the system to the end which has variable volume dispensing settings. The cocoyam is measured into the proper setting's size and then dispensed into the rolling vessel for further processing.

5..2.1.1 Existing Design #1: Spoon Dispensing

The traditional preparation of this dish features an individual using intuition and visually determining the amount of cocoyam to dispense into a leaf. In this design, there is a bowl or some large container that holds all the cocoyam that will be prepared into the dish. The individual then inserts the spoon into the bowl and will scoop the desired amount of cocoyam for the leaf that has been previously prepared for the next rolling step. As the current method that is utilized, it meets many requirements such as reliability, durability, lightweight, low cost, safe to use, simple, and mobile. However, since the client wanted to improve upon this system, the goal is to improve upon specifically the speed and adjustability of the dispensing of this method.

5..2.1.2 Existing Design #2: Server 88750 Single Dry Food Dispenser 2 Liter

Figure 22: Server 88750 [25]

The Server 88750, as shown in Figure 22, is a device that utilizes a simple handle to actuate the dispensing mechanism, It has a 2L capacity which allows for the storage of the product to be dispensed. The dispenser is also capable of being mounted and being removed for cleaning. Since the device is self-contained, it meets the safety requirement. The device is also simple as the handle is a common device, reliable since these types of devices are common, and lightweight due to the plastic material. However, where this device lacks is the adjustable dispensing and its cost. [25]

5..2.1.3 Existing Design #3: Bulk Food Dispenser

Figure 23: Bulk Food Dispenser [26]

This bulk food dispenser, as seen in Figure 23, is similar to the Server 88750. There is a handle that is actuated by an individual in order to begin the dispensing process. Product is dispensed from a reservoir and out the nozzle. This design differs from the Server 88750 in that it is placed at an incline, which can assist with the flow of product out of the nozzle. This design meets the requirements of safe to use, simple, lightweight and mobile due to not requiring the device to be mounted. However, the device is not adjustable in dispensing a set quantity and the cost of the device. [26]

5..2.2 Subsystem #2: Rolling Mechanism

In this subsystem, cocoyam has been dispens**ed into a leaf that is prepared in the rolling device. The device then moves the leaf with the cocoyam through the rolling process so that the final product is the cocoyam wrapped tightly within the leaf and is then the final dish, Ekwang and Kwacoco Bible, that is now able to be removed from the system and placed into a different vessel for cooking.**

5..2.2.1 Existing Design #1: Hand Processing/Rolling

The current traditional method of completing the rolling is by hand. The individual secures the cocoyam in the leaf and forms it into a cylinder along an outer **edge of the cocoyam. The edge is then folded down to create the first portion of the roll into the cocoyam. The cocoyam and leaf are spun along an axis as the individual holds onto the combination. This process of rolling continues until the entire leaf encapsulates the cocoyam and the final dish, Ekwang, is now ready to be transferred for cooking.**

5..2.2.2 **Existing Design #2: Kitchen Magic Roll Sushi Maker Meat and Vegetable Rolling Tool**

Stuffed Grape & Cabbage Leaf Rolling Machine

Figure 24: Dolma Roller [27]

This device in Figure 24 was referenced by the client as a preferred device to base the final design off of. This rolling machine features a plastic base with a handle and belt to wrap the contents placed on the device [27]. This device meets certain requirements including safe to use, simple, low cost, lightweight, and mobile. However, the device is not durable and the leaves must be of a certain size and type (grape leaves) which does not suggest easy use with a variety of filling volumes, which would be dispensed into this device from the dispenser subsystem.

5..2.2.3 Existing Design #3: Yomo Maker Kit

Figure 25: Yomo Maker Kit [28]

The device in Figure 11 is used to create sushi rolls that are consistent. Depending on the amount that the device is filled will vary the diameter of the final product. This device assumes that there is a certain area of the base wrapping material in order to create the roll. Because of the size of the roll for the Ekwang, this system would be too large for this specific dish. Additionally, the action of rolling is not a fluid rolling motion but rather a wrapping, multi-motion movement. This device meets some requirements, including safe to use, lightweight, and mobility. However, it is not a simple process to roll, is not faster than the traditional method, and may not reliably produce the same size product. [28]

5..2.3 Subsystem #1: Reservoir

Prior to being dispensed, the cocoyam is placed in a reservoir of sorts. From this reservoir, it is then dispensed and rolled into the final product.

5..2.3.1 Existing Design #1: Bowl

The current system in as demonstrated features a bowl as the vessel that contains the cocoyam mixture. It is simple but effective. Depending on the amount that is desired to be prepared, an individual may use any size bowl that is available at the time of preparation. This meets all requirements, granted that the bowl being used is a robust material, and the bowl was clean prior to use.

5..2.3.2 Existing Design #2: Funnel

Figure 26: Nopro Plastic Funnels [29]

Another possibility for housing the pre-rolled cocoyam is a funnel. A simple plastic funnel, like ones made by Nopro in Figure 12, allow for a variety of sizes to contain the cocoyam *[29]*. This design would require a direct connection to the dispensing mechanism because of the hole on the bottom which allows for the transfer of materials through a smaller cross-sectional area. This design is low cost, safe, simple, and mobile. However, the volume a funnel is able to hold is related to the cost, and therefore a funnel large enough to contain as much product as the client wants would increase the price. Additionally, some funnels are thin and not durable enough to handle pressure and constant reuse.

5..2.3.3 Existing Design #3: Hopper

Figure 27: Tremie Hopper [30]

The Tremie Hopper in Figure 13 features a square shaped base and circular opening [30]. The opening can also be cut to create a larger opening for faster discharge. This hopper is similar to a funnel, except it is much larger and is angled to the opening using a trapezoidal shape rather than a cone like a traditional funnel. This model in particular is over budget on its own, but provides another shape to reference when generating concepts. The client also specified that this shape is much easier for the African communities to recreate, and he would prefer this shape to others when designing a hopper opening on the system. This design does not meet certain requirements including weight, cost, and mobility. This design does meet other requirements including reliability, durability, safe to use, and simplicity.

6 DESIGNS SELECTED – First Semester

This section details how the team evaluated concepts and did design selection. The team started with very broad customer requirements which were then translated into engineering requirements and used to rank each design. Tools such as the gallery method, Pugh charts, and decision matrices were used to select a final design. Due to the system consisting of two unique parts the roller and dispenser, the team chose to do two of each evaluation method for those parts. Doing two of each evaluation method allowed for the most applicable criteria to be applied to each system. Once this one was done the winning design from each was combined into a final design and represented with a CAD model.

Technical Selection Criteria

To identify the key technical requirements the team met with the customer and disused the overall scope and wishes of the project. Mr. Zama stated during this time his desire increase number of Ekwang that could be rolled, that he wanted a cheap but durable device that could both measure and roll the Ekawg, along with a device that was simple and safe to use and under forty-five dollars. With these in mind the team created the following engineering requirement: minimize number of parts, multiple dispenser settings, low cost to build, and minimize time to produce one roll. Minimizing the number of parts along with decreasing the time to roll one roll were picked as the most important requirements.

The customer requirements were then placed into the Pugh charts, available in Appendix A and B, one for the roller mechanism and one for the dispensing mechanisms. The criteria used to evaluate the designs in the Pugh charts were the customer requirements. The customer requirements used were: reliability, durability, safe to use, speed, and adjustable dispensing/roll size. The designs the team created using the gallery method were them compared to the datum of a spoon and hand rolling. Once the designs were ranked using the customer requirements, the designs were then placed into a decision matrix and scored using the engineering requirements of design strength, low weight, capacity, minimize number of parts and low price. This allowed for the team to get a more quantitative result that closely match the need of the requirements. Decision matrices can be found in Appendix C and D.

Rationale for Design Selection

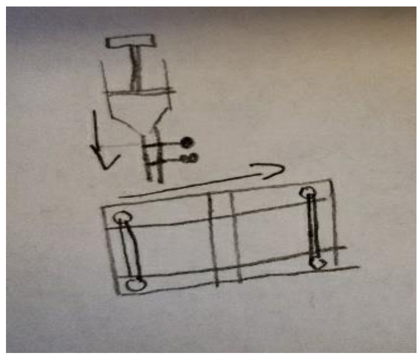


Figure 28: Full System Design 1

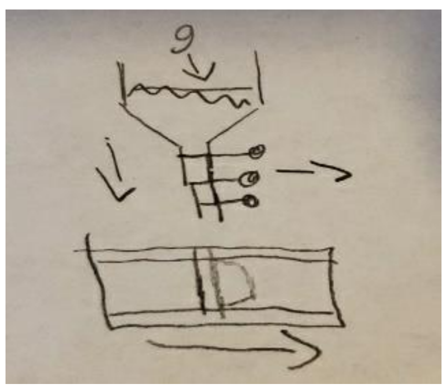


Figure 29: Full System Design 2

The top two designs that were selected after using the tools previously mentioned were full system designs one and two in Figures 28 and 29. These designs are very similar to each other with the main difference being the shape of the roller mechanism. These designs were the most plausible and efficient designs the team created. The Pugh charts and decision matrices used to evaluate the team's designs did not feature any full systems but the subsystems. Full system designs one and two are a combination of the highest scoring elements in each subsystems decision matrix. The first design features a plunger fed hopper that is metered using a gate system the feeds cocoyam onto a conveyer belt system that rolls the leaf. While the second design features a gravity fed hopper with a similar gate system that feed cocoyam onto a c shaped roller system. The first design excels in decreasing the time to produce one roll and can be easily taught to someone. The first design does struggle in the ease to manufacture and net weight of the design. The second design features a c shaped roller which allows for easy rolling along with a quick learning curve. This design struggles in the complexity of designing the c shape correctly to roll the cocoyam.

To further evaluate the designs a force calculation along with a costing calculation were performed. The force calculation modeled the handle and roller system. To do this the team treated the handle as a simply supported beam with a centralized 10lb force [31]. This allowed for the team to gather data on the expected forces the design might be subjected to. With the maximum amount of shear of .045kN in mind the team could also look into different material and choose the best for this scenario. See Appendix E for diagrams.

The next calculation the team did was a costing calculation. The cost to build the device was dependent on the material selected. The initial estimates using stainless steel were in the hundreds of dollars range while using abs plastic with a 10 percent infill was only around fifty dollars. With the force calculation, the team was able to determine that abs plastic would be sturdy enough to build our product out of. To further lower the price, the team wanted to pick the design with the minimum number of parts to use less material.

After considering all these factors, full system design two scored the highest out of all the deigns. This design is robust and safe while also being relatively affordable to manufacture. The C shaped roller will be somewhat complicated to perfect but offers the quickest way to uniformly roll the cocoyam. This design also closely represents the customer requirements and suggestions the best.

7 Risk Analysis and Mitigation

The team analyzed potential risk throughout the project and made decisions in the prototypes and final product that aimed to address the major concerns of the project. The team evaluated various trade-offs involved with the decisions made and created the final product.

Potential Failures Identified Fall Semester

Table 4: Shortened FMEA

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
1	Base deformed	Deflection of base	Excessive downward forces	48	Avoid excessive force
1	Base coming apart	Feet unstable/unfunctional device	Weld break/bracket disassembly	30	Replace brackets
1	cracking of the base	Inability to roll	Corrsoion	8	keep the base dry
2	Deform of side rail	Misalignment of rolling	Wear of device/improperly maufactured/improper assembly	10	Replace device
2	breakage of side rails	Misalignment of rolling	Excessive downward forces on the rail	72	Replace Rails
3	Fasteners Breakage	Disassembly	Excessive shear force	8	Replace brackets
3	Fasteners Loosen	Excessive wear/misalignment	Vibration/improper assembly	36	Fasten brackets properly
4	Detach from base	Belt is detached	Not fastened properly	30	Fasten brackets properly
4	Bends	Belt has less clamping force/becomes loose	Tension (pulling) from belt	6	Replace brackets
5	Blockage	Inability to secure the roll from unfolding	cocoyam builds up in the crevice	8	clean up the crevice
6	Handle breaks	Potential harm to user	Moment on handle	10	Replace handle immediately
6	Deforms	Potential harm to user	Excessive force from handle	20	Replace handle immediately
7	Bracket not assembled/loosened	Handle detached	Fastener dislodged	40	tighten handle
7	Handle instability	Handle detached	Bracket opening deformed	24	Replace brackets
8	Fracture of bar	Potential harm to user/unfunctional device	Excessive force from handle	10	Avoid excessive force
8	Bar dislodged from rails	Inability to roll	Uneven applied force	28	Avoid excessive force
9	Belt rips	Inability to roll	Wear of device/belt is torn	60	Replace belt
9	Detach from bracket(s)	Belt is loose	Not fastened properly	12	Reattach belt
10	Bolt loosened	Handle loosened	Not fastened properly	24	Fasten Bolt
10	Bolt Corrosion	breakage of bolt	Wear of bolt	4	Replace bolt
11	Blockage of nozzle	No dispensing of product	Clogging	128	Monitor consistency of product
11	Leakage of cocoyam	Wasted product	Seal breaks	36	Replace Nozzle
11	Breakage of nozzle	Unable to dispense	Corrosion	16	Replace Nozzle
11	Fracture of nozzle	wasted product	Leakage of cocoyam	8	Replace Nozzle
12	Cylindrical tube bending	Deflection/plastic deformation of the cylinder	Accidental drops	32	Avoid Dropping the device
12	Breakage of cylinderical tube	Inability to dispense	Dropped multiples times	20	Replace tube
12	Fracture of cylindrical tube	Leakage of cocoyam	Accidental drops	24	Replace tube
13	Handle breaks	Potential harm to user	Excessive force on handle	10	Replace handle immediately
13	Handle deformation	Inabilty to dispense	Excessive force on handle	20	Replace handle immediately
13	Bolt loosened	Detachment of the handle	Excessive force on handle	20	Tighten bolts
13	Spring deformed	Inability to despense	Excessive force on handle	20	Replace spring

This section focusses on the risks based on the FMEA, which can be found in Appendix A. A shortened FMEA is available above in Table 2. These failures modes are ranked based on the RPN, which is generated from multiplying severity, occurrence, and detection. The subsystem is broken down into three subsystems. The three subsystems are the roller base, roller, and caulking gun dispenser. Each subsystem is broken down into the function of each part within the subsystem. Each function has a potential failure mode and effects. Based on the potential failures and the effects, the severity, occurrence, and detection are determined. Many of the original failure modes are the same, including failures regarding the roller base. However, there are new failure modes relating to the dispenser due to the design changing from an original design to a commercial component. In the next subsections, the failures are represented based on the RPN from the highest to the lowest.

7..1 Potential Critical Failure 1: Caulking Gun - Blockage of nozzle RPN= 128

The highest potential critical failure was the blockage of the nozzle through the dispenser subsystem. This subsystem has the highest RPN of 128. This potential failure would be caused through the clogging of the nozzle of the dispenser. This failure could cause the whole system to stop dispensing the cocoyam product. Visual inspection could be conducted to indicate the potential failure. To overcome the blockage of the dispenser's nozzle, the user should monitor the consistency of the cocoyam while dispensing.

7..2 Potential Critical Failure 2: Roller Base - breakage of side rails RPN =72

The breakage of the side rails throughout the roller base subsystem has second highest RPN number of 72. This potential failure is caused due to an excessive amount of downward forces on the side rails, which could cause a misalignment of the rolling process of the cocoyam across the rails of the roller base. This potential failure could be indicated by a visual inspection on the sides of the device. By replacing the side rails on the roller base as an immediate action would solve the failure.

7..3 Potential Critical Failure 3: Roller - Belt rips RPN = 60

The belt rips of the roller subsystem are one of our main potential failures. This is a critical failure because it causes the belt to be torn or worn. This potential failure is caused due to an excessive downward force on the belt. This potential failure will cause the whole process to be paused due to the inability of rolling the cocoyam due to a ripped belt. This potential failure could be indicated through a visible inspection of the belt frequently. As a recommended action, a change of the belt is required as soon as possible.

7..4 Potential Critical Failure 4: Roller base - Base deformed RPN = 48

Deformation of the Roller base is the fifth potential failure with an RPN value of 48. The base of the roller is deformed due to an excessive downward force from the user. This failure will cause a deflection in the base of the roller. This failure is simply detected by a visual inspection from the user. Avoiding an excessive amount of force will simply overcome the deflection.

7..5 Potential Critical Failure 5: Roller - Bracket not assembled/loosened RPN = 40

The Roller brackets is one of the potential failures with an RPN value of 40. This failure mode will cause the handle to be detached from the roller due to the fasteners dislodging. This potential failure is easily detected by a visual inspection of the device. Tightening the handle and fastening the brackets will help in preventing the handle to be detached.

7..6 Potential Critical Failure 6: Roller base - Fasteners Loosen RPN = 36

Fastener in the roller base are a main component part in our design. This potential failure has an RPN of 36. The failure is caused by a simultaneous vibration as well as not properly assembled. This potential failure will cause and excessive wear of the fasteners additionally a huge misalignment o the roller base. A frequent visual inspection of the fasteners will detect the weariness of the fasteners. Fastening the brackets properly would overcome the issue.

7..7 Potential Critical Failure 7: Caulking Gun - Leakage of cocoyam RPN = 36

The leakage of cocoyam in the caulking gun has a low potential failure of 36 RPN. The seal breakage will cause the cocoyam leakage. The failure will result in wasted cocoyam which is not sever in comparison to other failures. The seal breakage can be visually inspected. In case this failure occurs replacing the nozzle is recommended.

7..8 Potential Critical Failure 8: Caulking Gun - Cylindrical tube bending RPN = 32

The caulking gun bending failure is a relatively low risk with an RPN of 32. The failure is caused by accidentally dropping the caulking gun from over the counter. This failure of the cylindrical tube will cause the caulking gun tube to be bended in which will result in either deflection of the tube or causing the tube to be deformed. This failure is easily detected by a visual inspection. Avoiding dropping the device will overcome this potential failure.

7..9 Potential Critical Failure 9: Roller Base - Base coming apart RPN = 30

The roller base coming apart is one of the team most important failure with an RPN of 30. This failure is mainly caused by the weld of the base breaks or by the brackets that are attached to the base are disassembled. The failure of the base coming apart will cause the base to be unfunctional. This failure can be detected by a visual inspection. Replacing the base brackets would overcome this issue.

7..10 Potential Critical Failure 10: Roller Base - End Bracket RPN=30

The roller base end brackets are the lowest potential failure with an RPN of 30. The detachment of the end brackets would cause the belt to be detached from the roller base. This failure is caused because of the end brackets are not being fastened properly. To overcome this failure mode, fasten the brackets properly. This failure mode can be detected by a visual inspection.

Risk Mitigation

The largest risk trade-offs the team analyzed involved material selection. Most of the critical failures the team's design would be subjected to involve deformation. The initial design material chosen by the team was a plastic. Plastic would offer a lightweight building material while being relatively cheap. But with these positives come the ability to easily deform the material and increased complexity when building the design in Africa. So, the team opted to take a risk and make the design out of wood. Wood is rigid and allows for less deformation when using thinner sheets of material. With the current assembly facilities in Africa consisting mainly of wood working shops, choosing wood increases the ability for the design to be more easily recreated. The trade-off with this decision is the increased cost of the design along with an increase in the design's weight.

The top possible failures consisted of blockage of nozzle, breakage of side rails, belt rips and base deformed. All of these failures are interconnected with the amount of force being applied by the user onto the roller and caulking gun. The team chose a caulking gun due to its ability to be easily disassembled and cleaned. The nozzle can be easily disassembled and cleaned in case of a blockage. In addition, the breakage of the side rails will be difficult to occur with wood as wood is more rigid than plastic.

Many of the other failures revolve around improper assembly or the use of substitute materials. When creating this design, the team was diligent in finding materials that were readily available in Central Africa as well as the United States. Once these materials and fasteners were found they then could be used in the design. Even with this research, the team runs the risk of the manufacturer substituting in different materials and fasteners that may look similar but do not share the same material properties. The use of improper fasteners can cause critical failures such as the assembly coming apart, wear due to loose tolerances, or damage to other components. The team's decision to implement staples as an a form of fastening, in addition to some bolts, is a potential new risk. Users lose the ability to disassemble the roller in its entirety once fully assembled. This may lead to more difficulties cleaning if cocoyam were to be spilled over the entire device. However, the team determined that the trade-off of having a device that is more intuitive to put together, simpler, and cheaper due to a decrease in hardware outweighed any potential negative results. The use of other fasteners will not affect the devices functionality unless they are not properly tightened. The use of the wrong material can cause the device to corrode or fail prematurely. By properly educating the users on how to assemble and maintain the device the team will likely prevent any of these failures making the risk worth it.

8 Testing

Testing Procedures (TPs)

Tests will be run on the device to evaluate the designs ability to meet the engineering requirements. Test for each requirement was formulated to test the ability of the design to adhere to the tolerances specified. Test such as drop, smooth edges, and roll production or are hands on while software analysis test were completed using computer software. The description of the test a long with the resources need for each are provided below.

8..1 Testing Procedure 1: Roll Production Time

In the Roll Production test, the engineering requirement of rolling one roll in 30 seconds or less will be evaluated. Using the final prototype, the team will use volunteers that have little instruction to see how long it takes them to produce one roll. The uneducated volunteers will represent children first learning how to use the device. This test will take place after the final assembly and drop test of the team's device.

8..1.1 Testing Procedure 1: Objective

After final assembly has been completed, a set of ten volunteers will be gathered. The volunteers will be given brief instruction on how to use the device. Cocoyam leaves will be prepared ahead of time with the cocoyam paste spread to the correct dimensions. Each volunteer will be handed the prepared leaf and asked to roll it using the device. The timer will be started once the volunteer is handed the leaf and stopped once the roll is completed and in the divot in the roller base. If the volunteer completes a roll in under 30 seconds the test is passed any time over 30 seconds the test is failed. If the test is failed the user will be given additional instruction. If the test is still failed the areas of inefficacy will be reviewed. This test uses time to test the ability of the user to quickly learn and operate the device.

8..1.2 Testing Procedure 1: Resources Required

Table 5: Resources for Test 1

Resources	**Description**	**Obtain Resource**
People	Volunteers varying in age	Free, voluntary participants
Timer	Stopwatch to measure time to roll	Free, phone timer
Cocoyam Paste	Grated cocoyam and spice mixture	Buy, specialty market
Device	Device completely assembled	Buy, the final product
Location	Any available space	Free, public space

8..1.3 Testing Procedure 1: Schedule

Each test will take roughly one minute. If addition instruction is need it make take up to three minutes. This test will be conducted after the edge test and final assembly. The team plans to run this test during week six of the semester.

8..2 Testing Procedure 2: Drop Test

A drop test will be performed to evaluate the strength of the design and the design’s durability. Testing will consist of pushing off or dropping the device from a surface approximately 0.5m high. The distance is representative of the carrying height of a person. Running this test after complete assembly and the smooth edge test allows the team to test the device under more accurate conditions. Running the test before the edge test may subject the device to higher stress concentrations on any surface that is not radiused. If deformation does occur during the drop test the edge test will be performed again after the surfaces are refinished.

8..2.1 Testing Procedure 2: Objective

To start the test the device will be placed on a countertop approximately one meter from the ground. A team member will then push the device of the edge of the counter causing the device to impact the ground. After the device impacts the ground it will be checked for deformation. If the device has any broken parts or deformation that causes the device not to function the test is failed. If little or no deformation occurs the test is passed. This test will be performed on both the roller and dispenser since they are both subject to being dropped. After the devices passes that section of the test a team member will hold the device with their arms parallel to the ground and drop the devices. Using the criteria from above the devices with be given a pass or fail. If the devices do not pass either portion of the test a redesign of the part will be conducted to increase the parts strength. The drop test is testing the strength of the device along with its resistance to deformation. The test does this by subjecting the device to similar amount of force the device may see in use or if dropped.

8..2.2 Testing Procedure 2: Resources Required

Table 6: Resources for Test 2

Resources	**Description**	**Obtain Resource**
People	Team Members	Free, self
Countertop	Approximately one meter high	Free, at home/98C
Device	Device completely assembled	Buy, the final product components
Location	Any available space	Free, at home/98C

8..2.3 Testing Procedure 2: Schedule

This test will take approximately ten minutes to complete. If the device fails it will take longer since repairs may be needed along with retesting. The team will complete this test after the edge test to reduce stress concentration on the edges. The edge test and full assembly must be completed before this test can take place. This test is scheduled to be completed during week eight.

8..3 Testing Procedure 3: Stability Test

The stability test will test the ability of the team's design to resist tipping over. Forces will be applied at predetermined locations on the device to see if the design falls over or is stable. The engineering requirement being tested is a low center of gravity. If the device has a low center of gravity it will not tip over with average size forces being applied. This test will be run first using SolidWorks to find the actual center of gravity and then in person after the drop test.

8..3.1 Testing Procedure 3: Objective

The first portion of this test will be to use SolidWorks to find the actual center of gravity of the device. The center of gravity will only be tested on the roller. Once the center is located a force will be applied to the top, bottom and middle of the roller as separate portions of the test. If the device tips over on any portion of this test the test is failed. If it stays up right the device passes the test. If failed the device will be redesigned in SolidWorks to lower the center of gravity. The amount of forced being applied will be measured by a pull gauge. The force will increase in increments of five pounds until 20 pounds is reached. Using this test quickly evaluates if the center of gravity is in the correct position to prevent any malfunctions while in use.

8..3.2 Testing Procedure 3: Resources Required

Table 7: Resources for Test 3

Resources	Description	Obtain Resource
People	Team members	Free, self
Pull Gauge	Gauge that can measure up to 20lbs	Borrow, from professor
Device	Device completely assembled	Buy, the final product
Location	Any available space	Free, 98C

8..3.3 Testing Procedure 3: Schedule

This test will take approximately ten minutes per device. Since the force will be applied multiple times in multiple locations it will take longer than the previous test. This test will be completed after all the other test since they may cause major design changes. The team has decided to test this during week eight.

8..4 Testing Procedure 4: Analysis Software Test

For the engineering requirements that can be validated with numerical values that either meet or fail to meet our goal values, software will be used. The engineering requirements being tested using software are factor of safety, mass (low weight), footprint, and cost. Using the properties tab in SolidWorks along with excel files specific to factor of safety and costing the requirements will be tested. The test will be evaluated on a pass or fail system.

8..4.1 Testing Procedure 4: Objective

The first portion of this test will be run using the properties tab in the SolidWorks files. Each of the engineering requirements has an acceptable value such as a mass less than seven kilograms and footprint under $0.5m^2$. The test will consist of comparing the goal values to the values in the properties tab. If the value is less than the desired the system passes if it is higher the system fails. If a part fails it will be redesigned to meet the desired value. For the excel portion of the test, a spreadsheet created to measure the factor of safety along with the bill of materials will be used. The requirements being tested for this portion are a factory of safety of the fasteners, and a total cost within the target range. The desired fastener's specification will be inputted in to excel spreadsheet where factor of safety is calculated. Using the bill of material and values from the properties tab in SolidWorks a total amount of material needed will be calculated multiplied by the cost of the material. For either to pass this portion of the test the must meet or exceed the factor of safety and be under the desired dollar amount. If they fail the test they will be redesigned and tested again.

8..4.2 Testing Procedure 4: Resources Required

Table 8: Resources for Test 4

Resources	Description	Obtain Resource
People	Team members	Free, self
Software	SolidWorks	Free, access on NAU computers/VPN
Software	Excel for factor of safety of fasteners, BOM	Free, access from Microsoft Excel
Device	SolidWorks Model	Free, created on NAU purchased software
Location	Any available space	Free, EGR building/anywhere on VPN

8..4.3 Testing Procedure 4: Schedule

This test will take approximately ten minutes with the largest amount of time being spent on the cost analysis. This test will not be run second semester but has already been completed during the first semester. This test was done first since it is critical in meeting many of the engineering requirements along with having the most effect on the overall design. The approximate date for this test is by the end of week six.

8..5 Testing Procedure 5: Smooth Edges

This test will verify that all edges of the device are smooth and will not cause any harm to the user. The engineering requirement being tested is smooth edges. The first portion of this test will be reviewing the SolidWorks files and making sure all fillets are within the determined acceptable range. Then using an inflated balloon, a team member will move the balloon across all the prototypes surfaces to see if it pops. This test will be completed after the final prototype is built.

8..5.1 Testing Procedure 5: Objective

After reviewing the SolidWorks part files, a balloon will be inflated to the point just before popping to allow for extra sensitivity. The inflated balloon will then be dragged across all surfaces and edges testing for smoothness. If the balloon pops the test is failed. If a part fails the test, it will be resurfaced so all edges will be sanded down to an acceptable range. After resurfacing, the test will be performed until all surfaces pass. This test is testing the smoothness of the edges and how safe the device is to use. This test simulates a user coming in contact will the surfaces of the design with the balloon popping being correlated with harm to the user.

8..5.2 Testing Procedure 5: Resources Required

Table 9: Resources for Test 5

Resources	Description	Obtain Resource
People	Team members	Free, self
Balloon	Party balloon style not water balloons	Buy, local store/Free, leftover from member

Device	Device disassembled so all surfaces are testable	Buy, the final product components
Location	Any available space	Free, at home/98C

8..6 Testing Procedure 5: Schedule

This test can take from a couple minutes to an hour if the device fails and need to be taken to the machine shop. The team will run this test once all the parts are manufactured. This test will be run at the beginning of week seven.

8..6.1 Testing Procedure 6: Dimension Test

This test will evaluate the dimensional parameters set by the engineering requirements. The parameters being evaluated for this test are weight and the base footprint. Since these factors directly impact each other, it is best to evaluate them at the same time.

8..6.2 Testing Procedure 6: Objective

Testing for these parameters will be done by inspection using SolidWorks. Using the final SolidWorks model the properties will be inspected for both a plastic and wood version. For the design to past it must fall within the tolerance for both materials. If the design does not fall within the tolerances the design will be modified to meet the tolerance set previously. It will also be determined by inspection using the prototype and final product.

8..6.3 Testing Procedure 6: Resources Required

Table 10: Resources for Test 6

Resources	**Description**	**Obtain Resource**
People	Team members	Free, self
Software	SolidWorks	Free, NAU computers
Device	Device disassembled so all surfaces are testable	Buy, the final product components
Scale	Basic scale	Free, member has resource
Ruler	Basic meter stick	Free, available through NAU resources
Location	Any available space	Free, Engineering building

8..6.4 Testing Procedure 6: Schedule

This test was partially conducted last semester once the final CAD package was completed. The test will be run again once the modifications to the CAD model are made. Physical measurements will also be made once final modifications are made to the device. This test will be run by the end of week six.

9 Standards, Codes, and Regulations

Table 11: Standards, Codes, and Regulation and How They Apply to the Project

<u>**Standard Number or Code**</u>	<u>**Title of Standard**</u>	<u>**How it applies to Project**</u>
ASTM A334/A334M – 04a (2016)	Standard Specification for Seamless and Welded Carbon and Alloy-Steel Tubes for Low-Temperature Service	This standard provides the requirements that alloy-steel tubing must conform to, which our main consideration for materials falls into this category
ISO 7045 (DIN 7985, ANSI)	Cross Recessed (Phillips) Pan Head Machine Screws	Provides requirements for fasteners (screws) that have been selected for use
ISO 7040 (DIN 985, ANSI B18.16.3M)	Stainless Steel Nylon Insert Lock Nut	Provides requirements for fasteners (nuts) that have been selected for use
ASTM UNS S31600	Type 316 stainless steel	Provides material requirements to adhere to stainless steel of 316 type, which is of heavy consideration for use
ANSI Z49.1:2012	Safety in Welding, Cutting, and Allied Processes	Safety is a major concern in use of the product, but should also be a major concern in the manufacturing of the product
AWS B2.1/B2.M-BMG:2014	Base Metal Grouping for Welding Procedure and Performance Qualification	Provides extensive information regarding potential materials and the standards that they fall into as well as some strength properties. Can be used to find alternatives to materials selected should the need arise in testing
21CFR110	TITLE 21--FOOD AND DRUGS CHAPTER I--FOOD AND DRUG ADMINISTRATION DEPARTMENT OF HEALTH AND HUMAN SERVICES SUBCHAPTER B--FOOD FOR HUMAN CONSUMPTION PART 110 CURRENT GOOD MANUFACTURING	Provides guidelines for human contact with food and food surfaces as well as maintenance in order to maintain general cleanliness/sanitary operation of surfaces. This aids greatly for the future operations manual portion of the project.

	PRACTICE IN MANUFACTURING, PACKING, OR HOLDING HUMAN FOOD	
FDA Food Code: 4-101	Chapter 4 - Equipment, Utensils, and Linens Part 4-1 - Materials for Construction and Repair Subpart 4-101 - Multiuse	Describes the characteristics a design must adhere to in addition to guidelines of specific materials' use limitations to maintain safe use.

The standards found range from material specific standards, to fastener standards, to assembly (welding) standards, and food safety standards. The material specific standards provide information regarding the materials that we have selected thus far. This also provides basic information including strength requirements of the materials, so the team has reasonable estimates when performing calculations. The fastener standards provide guidelines as to the sizing of the specific fasteners in order to adhere to the guidelines provided. This allows us to maintain reasonable tolerances on the holes in the parts without having to worry about clearances. Welding standards help to provide guidelines to the safety of welding as well as information that will be helpful when determining the ideal welding procedure. Food safety standards will be useful in the upcoming operations manual to ensure that the team considers proper usage and maintenance of the device to avoid harming anyone that uses the device. All of these are summarized by standard in Table 4 above

10 Calculations

FEA

With the current conditions the world is facing the majority of the teams testing procedure were not completed. Throughout the two semesters the team did do some software and physical testing on both the plexiglass and wood prototypes. A FEA was conducted using the SolidWorks software which resulted in an expected stress on the system Loading the system with 10 lbs of force in the simulation the team was able to see that the system did not reach its yield strength, passing this test. For all the other test run the system passed by not exceeding the allowable limit. The plexiglass prototype did exceed the max cost limit when paired with the most expensive dispenser. Using the cheaper dispenser, the plexiglass system passes the test. Table 2 below shows the results for all of the other test.

Figure 30 Test Results

	Calculated Results	Allowable
	Stress	
Plexiglass	3.457*10^6 MPA	98 MPA
African Mahogany	3.457*10^6 MPA	3.9 MPA

	Mass	
Plexiglass	0.9 kg	7 kg
African Mahogany	1.03 kg	7 kg
	Base Footprint	
Plexiglass	0.12 m^2	0.125m^2
African Mahogany	0.12 m^3	0.125m^3
	Force to Push Handle	
Plexiglass	0.90 kg	N/A
African Mahogany	0.90 kg	N/A
	Cost of Complete System	
Plexiglass	$54.02	$45
African Mahogany	$42.89	$45

The roll time was tested only using the plexiglass system. During this test the roll production time was below the 30 second time limit. The wood roller has the same geometry as the plexiglass allowing the team to assume the device will also pass. If the team had the opportunity, they would do all the test to give the client the best result. Overall, the device passed the test conducted and meets the durability and cost requirements set by the client.

Durability Test Calculation

After calculating the bending stresses at both the cut and the maximum moment location, the results were compared to the yield strength of the material which is the number that represents the last point that the material can deform elastically without breaking. Both African Mahogany and plexiglass were able to withstand the 10kg force without failing. Therefore, the prototype is durable and can be made from wood or plexiglass based on the client's preference.

	yiled strenght			yiled strenght	
plexiglass	64.8	Mpa	African Mahogany	6.9	Mpa
plexiglass	64800000	pa	African Mahogany	6900000	pa
check for failur due to bending	Does not fail			Does not fail	

Figure 31: Illustrate the excel sheet where the plexiglass and African mahogny are checked for bending failure.

Deflection Calculations

Deflection of the roller bar and the roller base was analyzed to determine if the current design would be able to withstand anticipated forces with minimal deflection. PLA plastic as well as wood were analyzed to account for the prototype material as well as the final anticipated material. After calculations were completed, it was deemed acceptable for both the roller bar and the roller base to remain as they are designed. Calculation sheets for both can be found Appendix G and H.

Force Requirement Calculation

Based on an analysis of the force requirement for the roller to move at a particular speed, the plexiglass model made from plexiglass and 3D printed material had a slight advantage when it came to the force requirement over the wood model. The ease of use and force calculation is one reason why the team is delivering both the plexiglass prototype as well as the wooden prototype. The final forces required at a given velocity is available in Appendix I.

11 Implementation

The implementation memo has a detailed information about the manufacturing process that the team has used to create the prototypes. In addition, the memo includes details on future manufacturing plans and design changes with a breakdown of the budget and schedule for the remaining time of the semester. The main changes in the design are to account for the imperfections in rolling, including the side rails that guide the rail bar. Moreover, the team has not decided on the handle for the wooden prototype, which is one of the main focus points in the design moving forward. The schedule main deliverable milestones are the manual as well as testing. The total budget left remaining is approximately $1182, or approximately three quarters of the total overall budget.

12 Manufacturing

Plexiglass Prototype

The team has manufactured two prototypes. The first prototype was made from plexiglass. The team determined that some sort of rigid plastic would be ideal to construct the first prototype, especially because the team has easy access to the Maker Lab in order to 3D print some of the parts with more complicated geometry and precise cutouts. The team determined to utilize plexiglass beyond the 3D printing due to easy accessibility and the convenience of the clear plastic to observe any issues with assembly after manufacturing, as well as plexiglass being cost efficient and light weight.

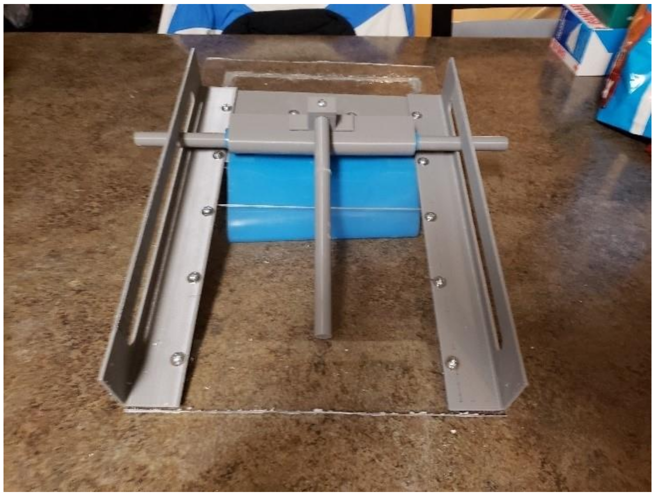


Figure 32: Plexiglass Prototype of Roller

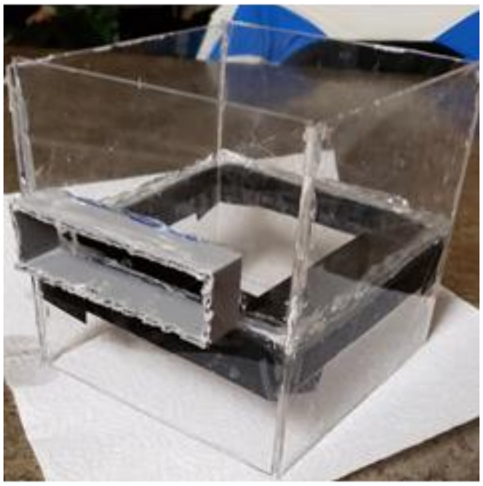


Figure 33: Plexiglass Dispenser

The team started manufacturing by breaking the plexiglass to meet the drawings that the team created in CAD modeling using the Dremel, which was primarily required in order to cut the plexiglass to size in terms of manufacturing, as seen in the base of the roller in Figure 31. The team also required fastening of the components for the original design of the roller and dispenser. For the roller, this was achieved through machine screws, washers, and nuts. Figure 32 shows the hot glue and tape that was used to assemble the sides of the plexiglass that were cut to size. In addition to cutting the base to shape, the team created holes using Dremel in the base for the fasteners. Beyond the manufacturing involving the plexiglass, the team required use of the 3D printers in the Maker Lab in order to print the side rails, the end bracket, the roller bar, the roller bar bracket, and the handle in this prototype.

Roller Wood Prototype (Final Design):

Beginning of the second semester of the capstone, the team has decided to build a second prototype based on the client request. The second prototype was manufactured from wood. The team ordered ½-inch plywood, a dowel rod, and ¼-inch plywood. Those materials were used by the team to manufacture the prototype based on the same dimensions that were used to manufacture the plexiglass prototype. First, the team used a table saw to cut the plywood into the dimensions required for the base, rails, and the falling hole for the roll to fall in, afterwards the team used the drill to drill out the holes where the base of the design were nailed with both of the side rails.

Figure 34: Wooden Roller

Figure 33 shows the completed manufacturing of the new roller base using the manufacturing processes above.

Caulking gun dispenser (Final dispenser design)

Figure 35: Caulking gun disassembled

The team came up with a new dispenser method due to the original design manufactured in the first semester not performing as expected. The new design is a simple caulking gun device purchased from Amazon with a price tag of less than twenty dollars. The caulking gun shown in Figure 2 has a three-stage disassembly process that is convenient for cleaning the dispenser. It was determined to be user-friendly due to the low number of components as well as the accessibility for cleaning the system to improve the food safety of the system.

Engineering Requirements Considerations

In regards to calculations and considerations involving engineering requirements for the project, the team considered the requirements detailed in the ERs, CRs, and TPs Revamp memo completed previously. For low weight, the team remained under the target weight of the roller for all the various prototypes, along with remaining within the bounds of the base footprint. Each entire system remains under budget when considering the cost to produce one product rather than the cost of bulk, raw materials. Smooth edges will be achieved once the team determines the most effective way of rounding out the edges on the wooden roller to prevent splintering. The center of gravity will be calculated via CAD software once the final, updated prototype has been fully designed in SolidWorks; the first prototype was determined to have an adequately low center of gravity so the team anticipates minimal change with the new material being implemented). The team has also completed various deflection and FEA calculations in order to determine appropriate thicknesses of the different materials in order to account for the factor of safety.

13 Design Changes Throughout Project

The design the team has settled on very closely represent the initial prototype made. Major changes stemmed from request from the customer along with the dispenser system not working properly. The team was ale to use previous concepts and new materials to meet the customers request and make all systems fully functional.

Design Iteration 1: Change in roller subsystem discussion

Figure 36: Low Fidelity Prototype

The very first low fidelity prototype is shown in Figure 35, which is a simple cardboard representation of the design intent of the team. This functioned as a proof of concept for the roller, which could roll stiff, cylindrical contents across the base of the roller. The team primarily encountered problems with the thickness of the mat used in the roller base. While the team was expecting to produce rolls approximately cm in diameter, the base was only capable of producing rolls that were double to triple this result; additionally, the inconsistency in the final rolled product was of concern to the team moving in to the higher fidelity model. There was also a large amount of deflection in the rails, which the team expected due to the base's construction out of cardboard.

The high fidelity prototype was constructed out of plexiglass and 3D printed materials, as described in the manufacturing section prior. The team implemented a new silicone sheet that was approximately 1/10th of the thickness of the original mat for the roller in order to produce as tighter roll. Additionally, the length of the track and overall dimensions of the base were reduced to more closely reflect the approximate 5cm x 5cm dimensions of the cocoyam leaves. The team assumed these dimensions could fluctuate up to approximately double (10cm x 10cm) considering the variability expressed when observing the demonstration during the first semester. Accordingly, the team factored in a total of 20cm of variability, with half of the tolerance applying to either side, and another approximately half of this half accounting for the space lost in due to fastening the rails. Other than the material changes and the dimensional changes, the design remained largely the same due to the performance of the device.

Figure 37: Wooden Prototype

The current design of the roller subsystem incorporates many changes. These are largely attributed to the manufacturing processes and fastening techniques used with yet another different material. The team was satisfied with the plexiglass prototype as it met the requirements, but the client expressed explicit interest in a wooden prototype not for mathematical engineering purposes, but because of accessibility in Africa to wood versus plastic. Because of this, the team has been working to create a wooden version of the design and is still in the process of performing final calculations to optimize the thickness of the material and the adherence to the safety factor before the final product. This design was made using the plexiglass prototype as a template for dimensions because the team had already optimized the dimensions as described above. The rails, as seen in the roller in Figure 6, are altered from the "L" shape in the previous design and instead are fastened to the side of the now thicker roller base in order to eliminate wasted material. The end of the roller was also shortened for the same purpose of eliminating wasted material due to that portion of the base serving no purpose in the previous prototype. The team is currently working through analyses to determine the optimal number of staple fasteners for the wood in order to produce a stable and reliable base.

The team was able to validate these design changes by using the Solidworks model to test for the design's stability. With one of the engineering requirements being stability the team used Solidworks to find the devices center of gravity. The new prototype had similar dimensions as the Solidworks model previously used. With the dimensions being the same the team was able to find the center of gravity and apply it to both models. If more drastic changes had been applied the team would have used another method in finding the devices center of gravity. As seen in Figure 7 the center of gravity for the device is exactly in the middle allowing for it to be very stable.

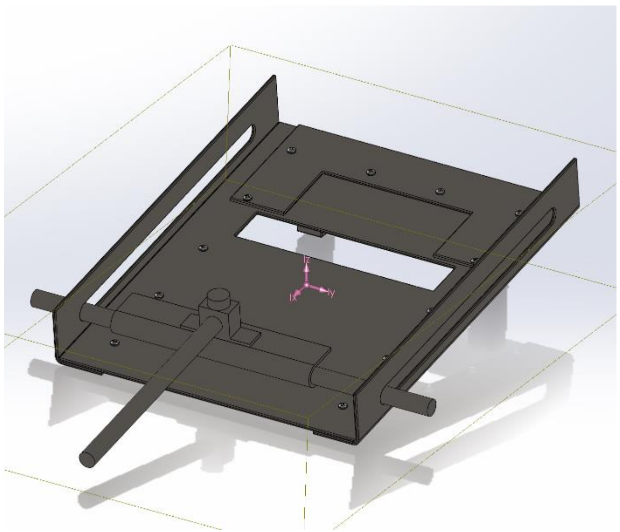


Figure 38: Center of Gravity

After this analysis the team was able to show that both models would meet this requirement. Further testing will be done on strength and its life cycle since the materials have very different properties.

Design Iteration 2: Change in dispenser subsystem discussion

Figure 39: Original Dispenser

The original design of the dispenser was much like the roller: composed of cardboard and very large, as shown in Figure 38. The team immediately knew the design needed to be scaled as well as made from a different material.

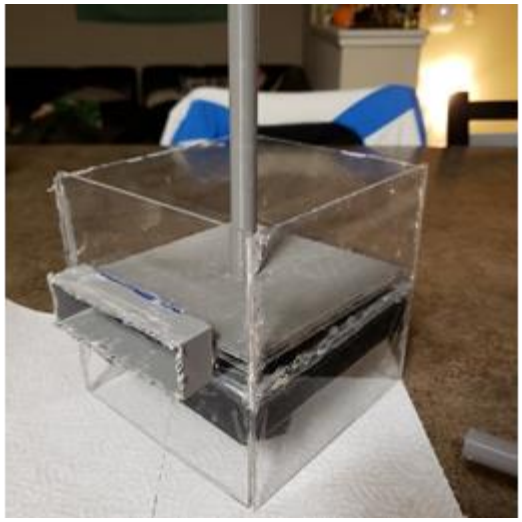


Figure 40: Plexiglass Dispenser

Figure 39 shows the same design scaled to a smaller sized to accommodate a smaller volume as well as the design being made out of a different material. The primary problem with this iteration was that the cocoyam mixture was unable to be forced out of the nozzle when pressure was applied to the handle of the dispenser. The force was distributing across the cocoyam and the small nozzle prevented flow through the system.

As discussed above, the team completely moved away from the initial dispenser to a caulking gun in order to overcome the back-up issue the team encountered with the nozzle. The caulking gun selected was selected for the easy disassembly/assembly for cleaning purposes, as well as the 12:1 mechanical advantage the gun provides. The team will be conducting an investigation as to the viscosity of cocoyam in the next few weeks as the equipment is available in order to determine the precise mechanical advantage that will be needed in order to dispense the cocoyam effectively.

14 Conclusion

This project ended quicker than expected due to uncontrollable circumstances, but the team was still able to provide the client with a robust device. Following design procedures, the team was able to create and modify a functional design into a real life product that will be used to serve African communities. The test that were conducted showed a functioning device that met the clients request along with meeting all engineering requirement. This project was rigorous and called on all of the teams previous engineering courses.

15 References

[1] Taroto Taiwanese Healthy Dessert, "Health Benefits and Nutrition of Taro Root," 2019. [Online]. Available: https://tarotodessert.com/en/2017/health-benefits-and-nutrition-of-taro-root/. [Accessed 18 September 2019].

[2] J. S. Hall, D. J. Harris, V. Medjibe and M. Ashton, "The effects of selective logging on forest structure and tree species composition in a Central African forest: implications for management of conservation areas," *Forest Ecology and Management,* vol. 183, no. 1-3, pp. 249-264, 2003.

[3] J. Bastin, N. Barbier and J. Bogaert, "Seeing Central African forests through their largest trees," *Scientific Reports,* vol. 5, pp. 1-8, 2014.

[4] L. Hurst, "West and Central African iron ore development and its impact on world prices," *The Australian Journal of Agricultural and Resource Economics,* vol. 57, pp. 521-538, 2013.

[5] B. Shah, "What Are Three Ways to Prevent Rust?," hunker.com, [Online]. Available: https://www.hunker.com/12146681/what-are-three-ways-to-prevent-rust. [Accessed 17 October 2019].

[6] "14 African Hardwoods – Their Properties and Uses," uWoodcraft.com, 16 February 2019. [Online]. Available: https://uwoodcraft.com/14-african-hardwoods/. [Accessed 17 October 2019].

[7] C.-C. Kao, "Automatic Egg Roller". United States of America Patent 3633517, 6 August 1970.

[8] A. Kadiogly and R. Terzi, "A dehydration avoidance mechanism: Leaf rolling," *The Botanical Review,* vol. 73, no. 4, pp. 290-302, 2007.

[9] B. Wang, W. Hu, L. X. Kong and P. Hodgson, "The influence of roll speed on the rolling of metal plates," *Metals and Materials,* vol. 4, no. 4, pp. 915-919, 1998.

[10] R. Cross, "Effects of surface roughness on rolling friction," *European Journal of Physics,* vol. 36, no. 6, 2015.

[11] J. Lenard, "Flat Rolling - A General Discussion," *Primer on Flat Rolling,* pp. 39-55, 2014.

[12] W. G. Smith, "Method and Apparatus for controllably Dispensing Powders and Liquids". United States of America Patent 6550640 B2, 22 April 2003.

[13] C. Young.Canada Patent 2998198, 25 January 1960.

[14] C. Vallance, Interviewee, *Capstone Advisor Meeting.* [Interview]. 12 October 2019.

[15] A. Bernstein, "Compound-Compressible Nozzle Flow," *Journal of Applied Mechanics,* pp. 548-557, 1967.

[16] e. Kuykendal, "Lighted Laminar Flow Nozzle". United States of America Patent 5160086, 3 November 1992.

[17] T. S. Awad, D. Asker and B. D. Hatton, "Food-Safe Modification of Stainless Steel Food-Processing Surfaces to Reduce Bacterial Biofilms," *American Chemical Society,* pp. 22902-22912, 2018.

[18] X. Shi and X. Zhu, "Biofilm formation and food safety in food industries," *Trends in Food Science & Technology,* vol. 20, pp. 407-413, 2009.

[19] P. Saravanan, S. Sathish Kumar, D. Visvanathan, S. Silambarasan and A. Charles, "Safe Food Packaging and Storage for Better Health and Environment," *International Journal of Integrative sciences, Innocation and Technology,* vol. 1, no. 5, pp. 1-4, 2012.

[20] C. Crockett and S. Sumar, "The safe use of recycled and reused plastics in food contact materials - part I," *Nutrition & Food Science,* no. 3, pp. 32-37, 1996.

[21] B. M. Burt, C. Volel and M. Finkel, "Safety of Vendor-Prepared Foods: Evaluation of 10 Processing Mobile Food Vendors in Manhattan," *Public Health Reports,* vol. 118, pp. 470-476, 2003.

[22] J. Nwana, Interviewee, *Cocoyam Phoenix Demonstration.* [Interview]. 19 Seotember 2019.

[23] Precious Kitchen, "Ekwang - Precious Kitchen - Ep 16," YouTube.com, 31 December 2016. [Online]. Available: https://www.youtube.com/watch?v=_CrGYcRaSTg. [Accessed 10 October 2019].

[24] Precious Kitchen, "Kwacoco Bible - Precious Kitchen - Ep 18," YouTube.com, 21 January 2017. [Online]. Available: https://www.youtube.com/watch?v=sLY8uwKkS0E. [Accessed 10 October 2019].

[25] ekuep, "Server 88750 Single Dry Food Dispenser 2 Liter," 2019. [Online]. Available: https://uae.ekuep.com/en/smallwares/serving-supplies/dry-food-dispenser-parts-and-accessories/server-88750-single-dry-food-dispenser-2-liter. [Accessed 18 September 2019].

[26] alibaba.com, "2018 China supplier plastic container bulk food dispenser mechanism candy dispenser for sale," 2019. [Online]. Available: https://www.alibaba.com/product-detail/2018-China-supplier-plastic-container-bulk_60641074197.html?spm=a2700.details.maylikeexp.3.720278ffYS0cN4. [Accessed 17 September 2019].

[27] G. Her and G. Roller, "Grape Leaves Roller", Must Have Stuff, 2019. [Online]. Available: https://musthavestuff.com/grape-leaves-roller/. [Accessed: 16- Sep- 2019]

[28] Yomo Sushi, "Sushi Making Kit by Yomo Sushi - Sushi in 4 easy steps," Amazon.com, 2019. [Online]. Available: https://www.amazon.com/Sushi-Making-Kit-Yomo-inches/dp/B00OAXPU5I. [Accessed 17 September 2019].

[29] Nopro, "Nopro Plastic Funne, Set of 3," Amazon.com, 2019. [Online]. Available: https://www.amazon.com/Nopro-Plastic-Funnel-Set-3/dp/B000HJBFC6. [Accessed 10 October 2019].

[30] Certified MTP, "Tremie Hopper," 2019. [Online]. Available: https://www.certifiedmtp.com/tremie-hopper/#fo_c=2799&fo_k=1073f51935146a9bf409053d3cba04a1&fo_s=gplaus?gclid=Cj0KCQjwoqDtBRD-ARIsAL4pviCxwrt9LBSanx5hq0-bcLBcov2FWWK6Xf2g6PIDBOztOAGpz4MjulYaAtXJEALw_wcB. [Accessed 10 October 2019].

[31] "SkyCiv Platform," Platform.skyciv.com, 2019. [Online]. Available: https://platform.skyciv.com/beam. [Accessed 8 October 2019].

16 APPENDICES

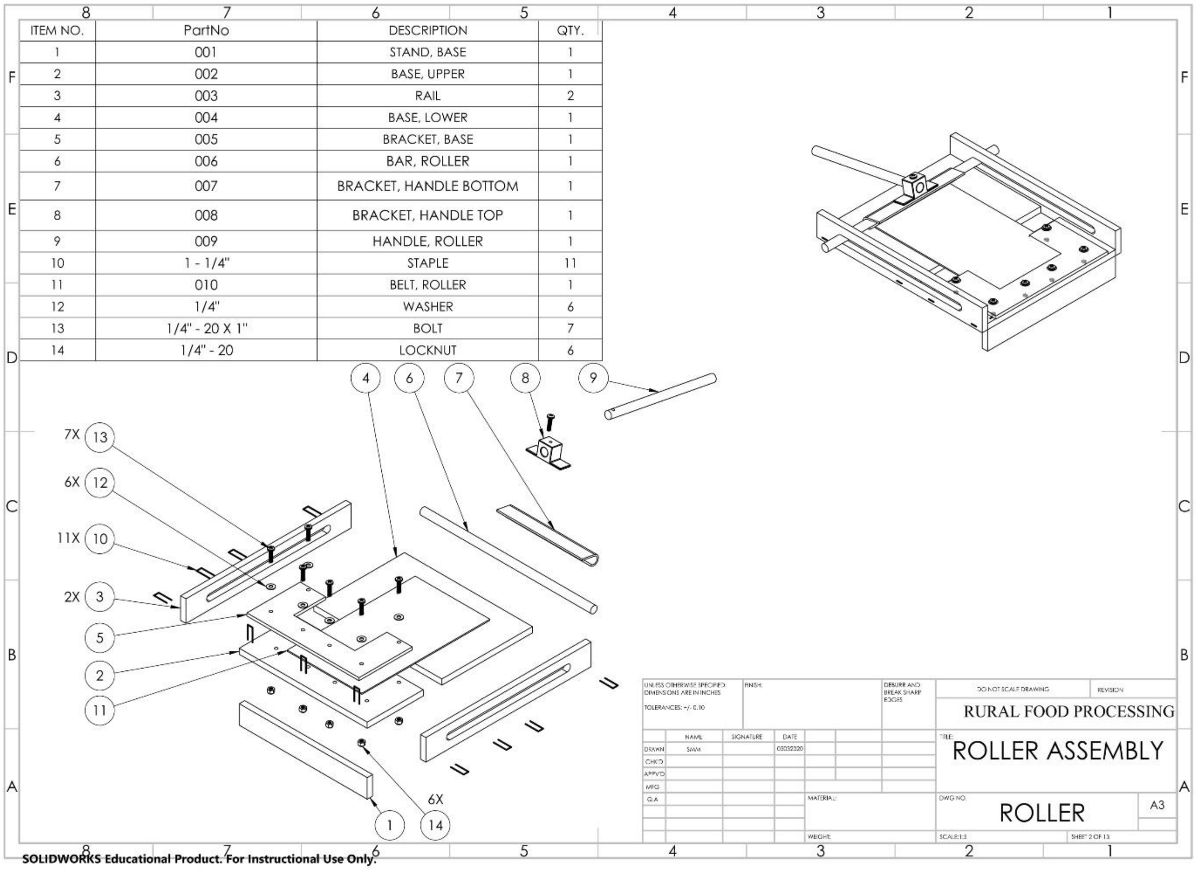
Appendix A: House of Quality

Customer Requirement/importance	Importance Ranking	Engineering Requirement	low weight	base footprint	volume of material to create device	smooth edges	low price	minimize time to produce one roll	material strength	material density	Low center of gravity	factor of saftey
1. realibilty	3		1	0	0	0	3	9	9	0	3	9
2. durability	2		3	0	0	3	3	1	9	3	1	9
3. lightweight	1		9	1	9	0	3	0	3	9	0	0
4. safe to use	3		0	0	0	9	0	0	3	3	1	9
5. simplicity	3		1	1	1	0	9	0	0	0	0	0
6. low cost	2		9	3	9	0	9	0	0	3	0	3
7. Easy to use by anoyne	2		1	0	0	0	3	1	0	0	3	0
8. mobility	1		9	9	9	1	0	0	0	3	1	0
9. faster than hand rolling	3		0	0	0	0	0	9	0	0	0	0
Absolute Technical Importance (ATI)			50	19	39	34	69	58	57	33	21	78
Relative Technical Importance (RTI)			11.8	4.1	8.5	7.4	15.1	12.7	12.4	7.2	4.6	17.0
Target ER values			7 kg	0.125 m^2	0.02 m^3	r=5 mm	$35.00	30 sec	44 MPa	1040 kg/m^3	-	3
Tolerances of Ers			>10 kg	>0.25 m^2	>0.1 m^3	<5mm	>$45.00	>60 sec	<44 MPa	<1040 kg/m^3	-	<3
Testing Procedure (TP#)			5	5	5	1	5	2	3	5	4	5

Appendix B: FMEA

Product Name				Development Team : cocoyam				Page No of			
System Name								FMEA Number			
Subsystem Name								Date			
Component Name											
Sub system	Part #	Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
Roller Base	1	Roller Base	Base deformed	Deflection of base	6	Excessive downward forces	4	Visual Inspection/Indication	2	48	Avoid excessive force
			Base coming apart	Feet unstable/unfunctional device	10	Weld break/bracket disassembly	1	Visual Inspection/Indication	3	30	Replace brackets
			cracking of the base	Inability to roll	8	Corrsoion	1	Visual Inspection/Indication	1	8	keep the base dry
	2	Side Rails	Deform of side rail	Misalignment of rolling	5	Wear of device/improperly maufactured/improper assembly	1	Visual Inspection/Indication	2	10	Replace device
			breakage of side rails	Misalignment of rolling	8	Excessive downward forces on the ra	3	Visual Inspection/Indication	3	72	Replace Rails
	3	Fasteners	Fasteners Breakage	Disassembly	8	Excessive shear force	1	Visual Inspection/Indication	1	8	Replace brackets
			Fasteners Loosen	Excessive wear/misalignment	4	Vibration/improper assembly	3	Visual Inspection/Indication	3	36	Fasten brackets properly
	4	End Bracket	Detach from base	Belt is detached	5	Not fastened properly	2	Visual Inspection/Indication	3	30	Fasten brackets properly
			Bends	Belt has less clamping force/becomes loose	3	Tension (pulling) from belt	1	Visual Inspection/Indication	2	6	Replace brackets
	5	Crevice in base plate	Blockage	Inability to secure the roll from unfolding	2	cocoyam builds up in the crevice	2	Visual Inspection/Indication	2	8	clean up the crevice
Roller	1	Handle	Handle breaks	Potential harm to user	10	Moment on handle	1	Visual Inspection/Indication	1	10	Replace handle immediately
			Deforms	Potential harm to user	10	Excessive force from handle	2	Visual Inspection/Indication	1	20	Replace handle immediately
	2	Handle Bracket	Bracket not assembled/loosened	Handle detached	5	Fastener dislodged	4	Visual Inspection/Indication	2	40	tighten handle
			Handle instability	Handle detached	4	Bracket opening deformed	2	Visual Inspection/Indication	3	24	Replace brackets
	3	Roller Bar	Fracture of bar	Potential harm to user/unfunctional device	10	Excessive force from handle	1	Visual Inspection/Indication	1	10	Avoid excessive force
			Bar dislodged from rails	Inability to roll	7	Uneven applied force	1	Visual Inspection/Indication	4	28	Avoid excessive force
	4	Belt	Belt rips	Inability to roll	10	Wear of device/belt is torn	3	Visual Inspection/Indication	2	60	Replace belt
			Detach from bracket(s)	Belt is loose	6	Not fastened properly	2	Visual Inspection/Indication	1	12	Reattach belt
	5	Bolts	Bolt loosened	Handle loosened	4	Not fastened properly	3	Visual Inspection/Indication	2	24	Fasten Bolt
			Bolt Corrosion	breakage of bolt	2	Wear of bolt	2	Visual Inspection/Indication	1	4	Replace bolt
Dispenser	1	Nozzle	Blockage of nozzle	No dispensing of product	4	Clogging	4	Visual Inspection/Indication	8	128	Monitor consistency of product
			Leakage of cocoyam	Wasted product	2	Seal breaks	3	Visual Inspection/Indication	6	36	Replace Nozzle
			Breakage of nozzle	Unable to dispense	2	Corrosion	4	Visual Inspection/Indication	2	16	Replace Nozzle
			Fracture of nozzle	wasted product	1	Leakage of cocoyam	2	Visual Inspection/Indication	4	8	Replace Nozzle
	2	Plunger base	Base plate bending	Deflection/plastic deformation of base	6	Excessive downward force	4	Visual Inspection/Indication	2	48	Avoid excessive force
			Breakage of base	Inability to dispense	4	excessive upward forces	2	Visual Inspection/Indication	1	8	Replace base
			Fracture of base	Leakage of cocoyam	2	Excessive downward forces	3	Visual Inspection/Indication	1	6	Replace base
	3	Plunger Handle	Handle breaks	Potential harm to user	10	Moment on handle	1	Visual Inspection/Indication	1	10	Replace handle immediately
			Handle deformed	inabity to dispense	10	Excessive downward forces	2	Visual Inspection/Indication	1	20	Replace handle immediately
			Handle Fracture	Potential harm to user	10	Excessive downward forces	3	Visual Inspection/Indication	1	30	Replace handle immediately
Reservoir	1	Reservoir/Hopper	Walls coming apart	Weld break	10	Excessive outward forces	1	Visual Inspection/Indication	4	40	Avoid excessive force
			Fracture of walls	leakage of cocoyam	2	Excessive outward forces	1	Visual Inspection/Indication	4	8	Avoid excessive force
			Breakage of walls	inability to hold cocoyam	3	corrosion	3	Visual Inspection/Indication	3	27	Replace Reservoir
			Deformation of walls	inability to use plunger	6	Excessive Angular forces	3	Visual Inspection/Indication	3	54	Avoid excessive force
			Corrosion of walls	Inability to use device	7	aging of material	1	Visual Inspection/Indication	1	7	Replace Reservoir
			Over flow	wasted cocoyam	1	Excessive cocoyam pouring	1	Visual Inspection/Indication	1	1	Input cocoyam steadily
			Scratching of the walls	Hiding microorganisms	4	Useage of wrong cleaning supplies	2	Visual Inspection/Indication	3	24	Use proper cleaning supplies
			breakage of bottom surface	wouldn't stand	6	Excessive downward force	1	Visual Inspection/Indication	1	6	Avoid excessive force
			wear of the walls	Inability to use	10	Force from plunger	1	Visual Inspection/Indication	1	10	Avoid excessive force
			Scratch of bottom surface	Hiding microorganisms	4	Force from plunger	2	Visual Inspection/Indication	3	24	Avoid excessive force

Appendix C: CAD Drawings



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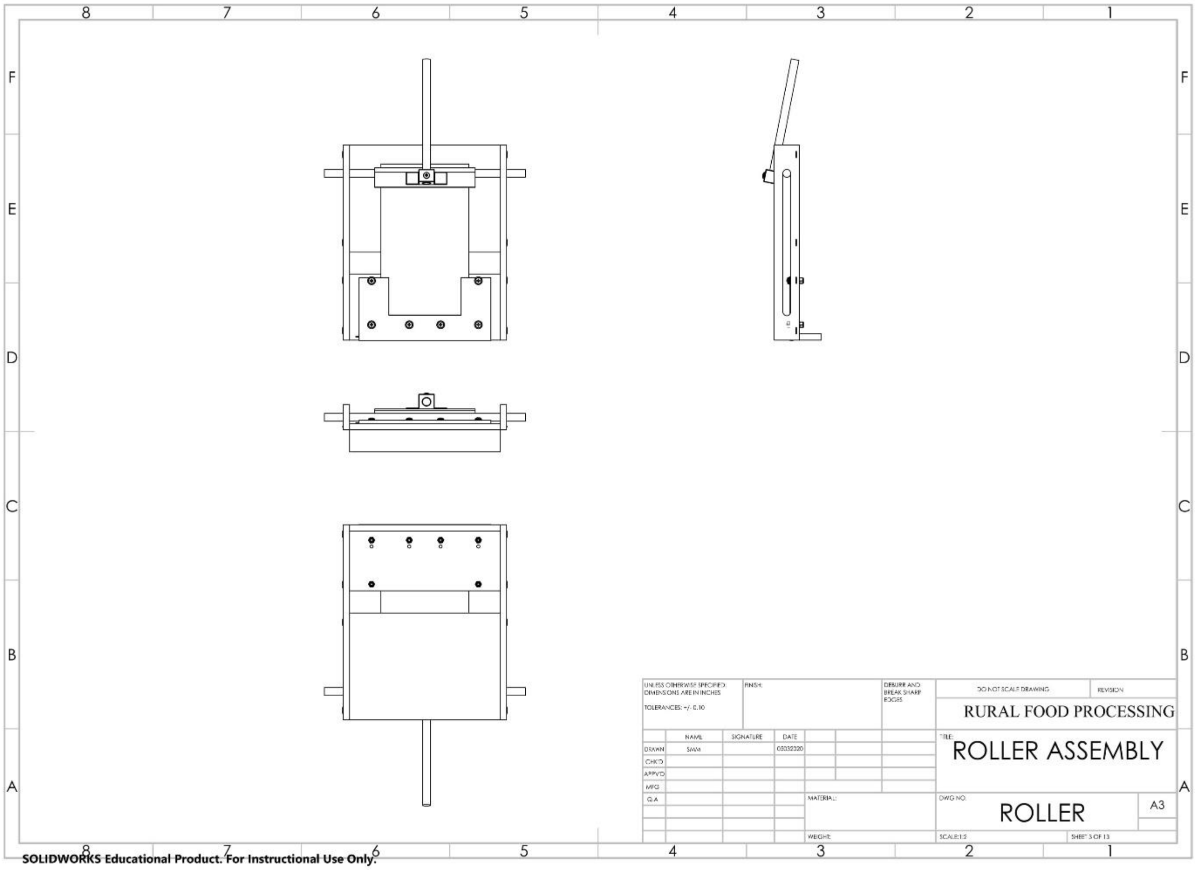
4	004	BASE, LOWER	1
5	005	BRACKET, BASE	1
6	006	BAR, ROLLER	1
7	007	BRACKET, HANDLE BOTTOM	1
8	008	BRACKET, HANDLE TOP	1
9	009	HANDLE, ROLLER	1
10	1 - 1/4"	STAPLE	11
11	010	BELT, ROLLER	1
12	1/4"	WASHER	6
13	1/4" - 20 X 1"	BOLT	7
14	1/4" - 20	LOCKNUT	6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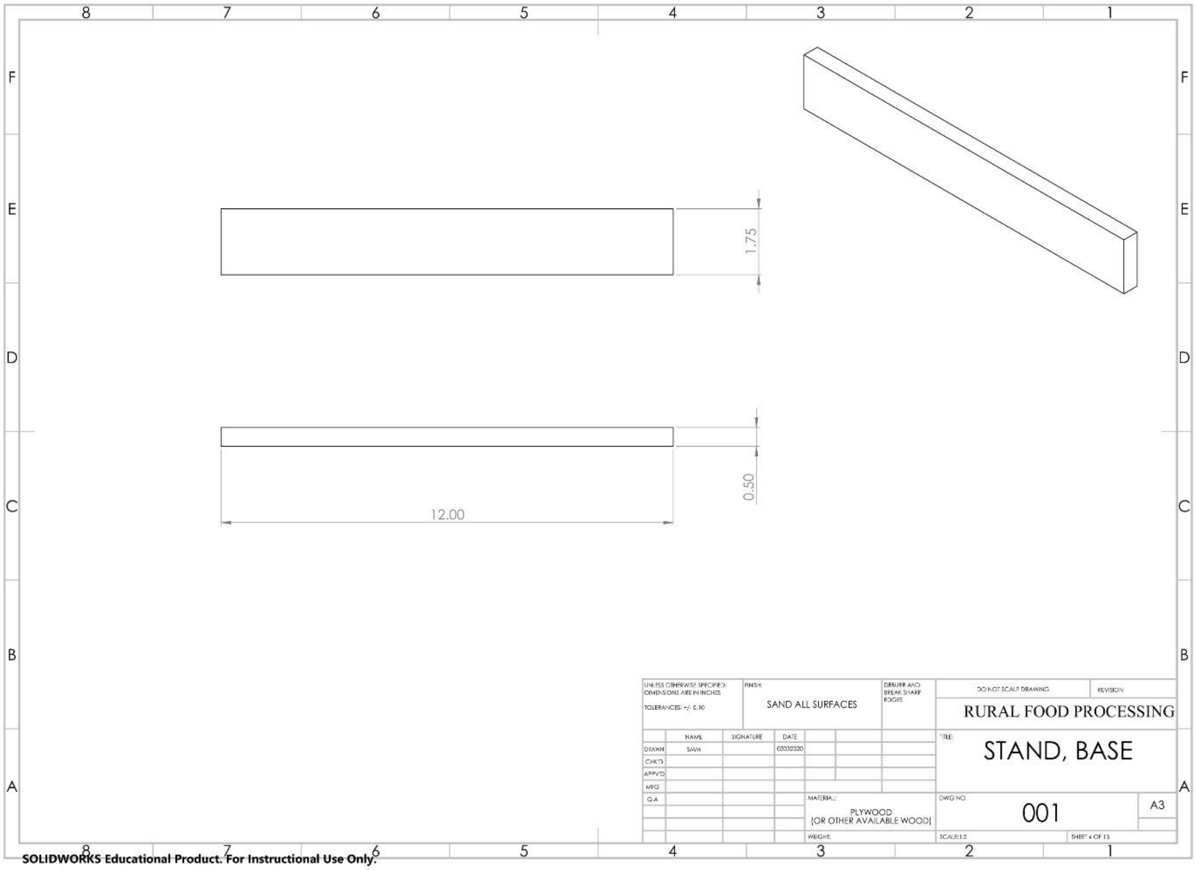
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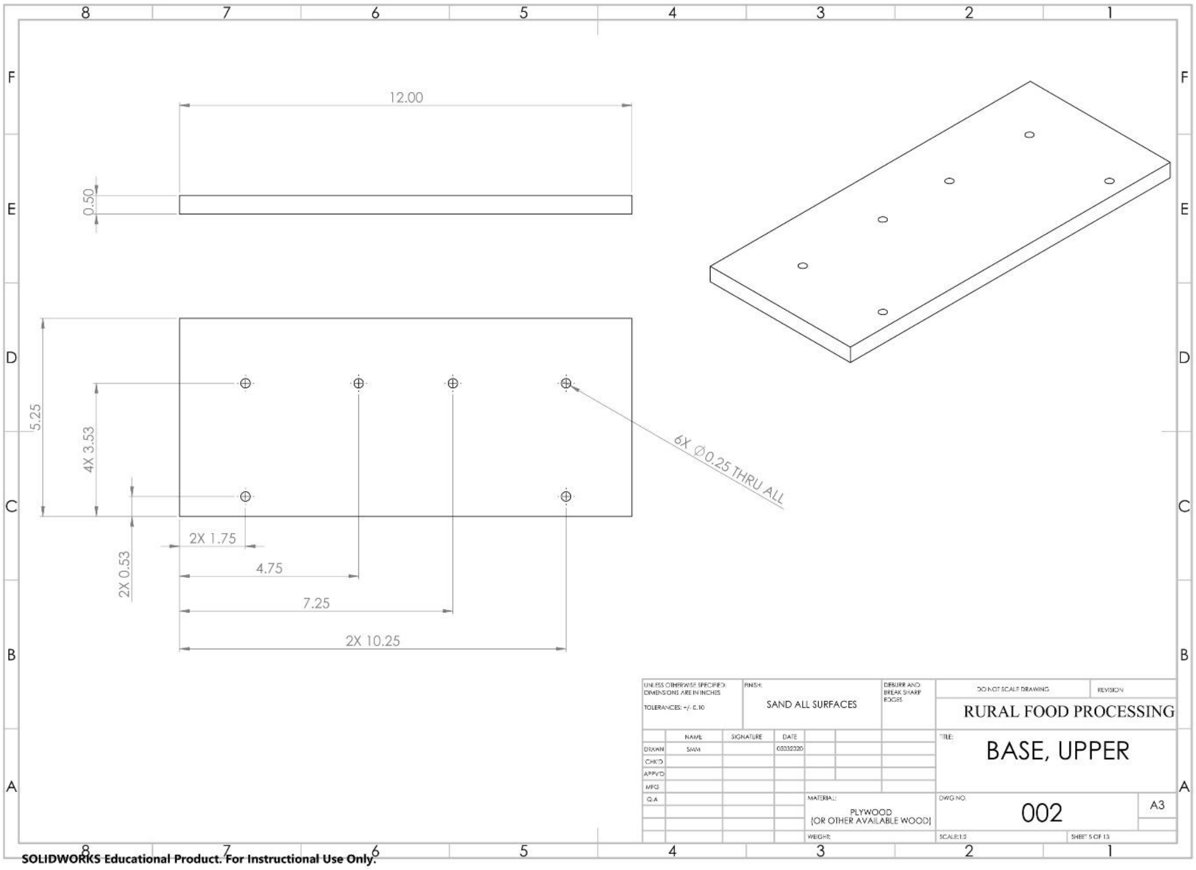
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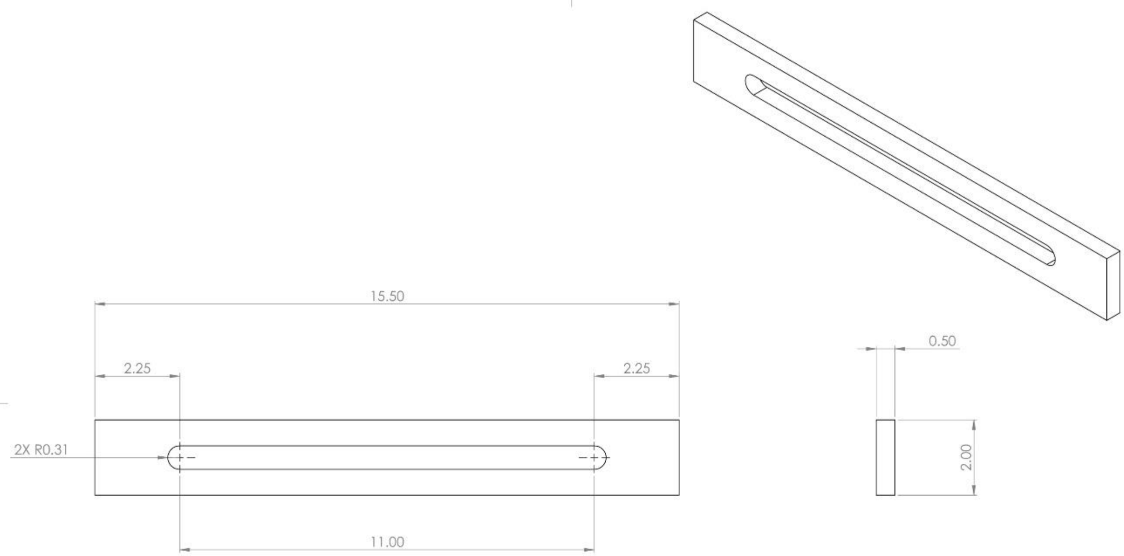

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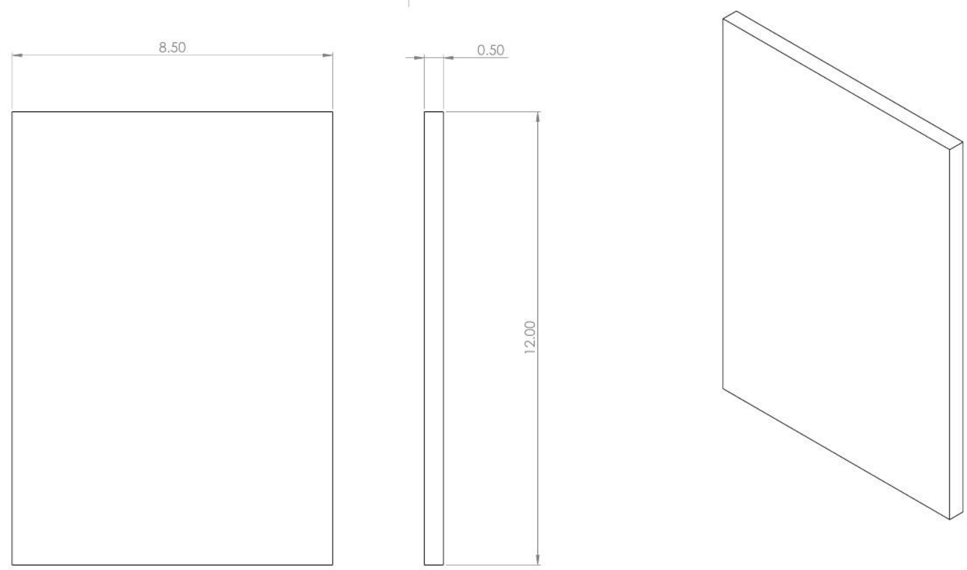

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RURAL FOOD PROCESSING

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MFG			
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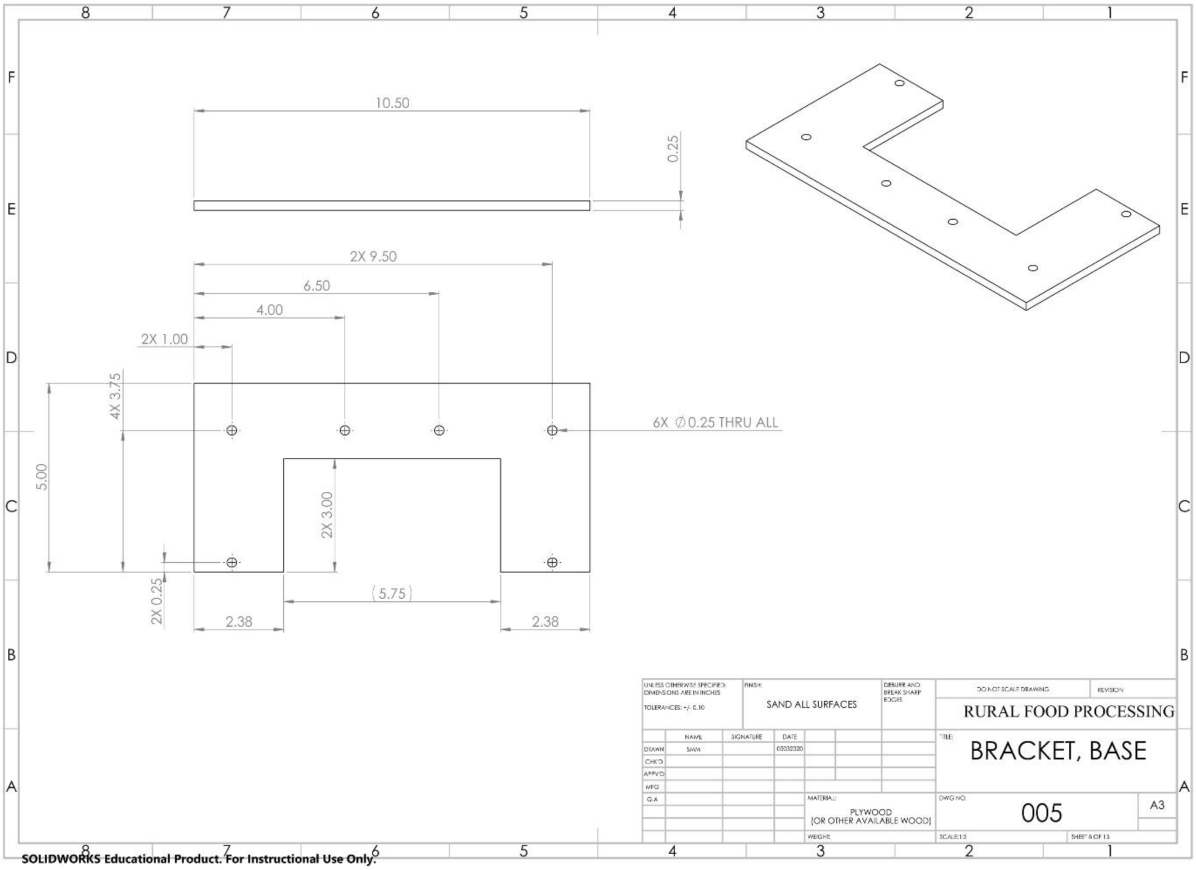
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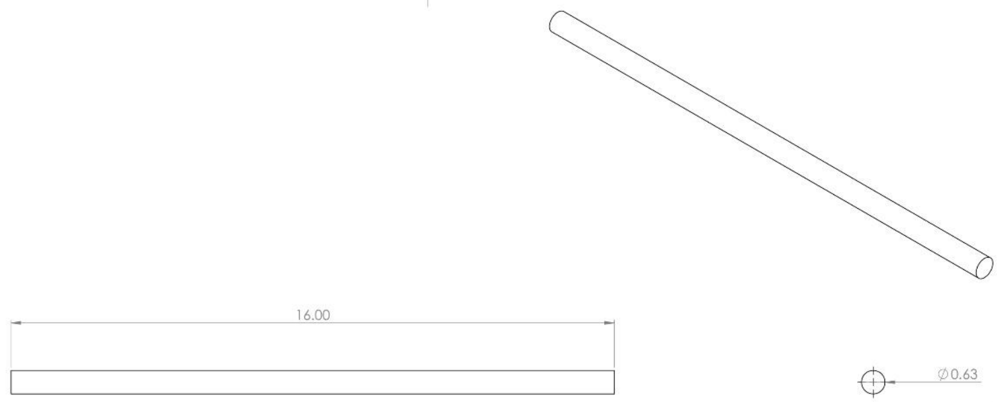

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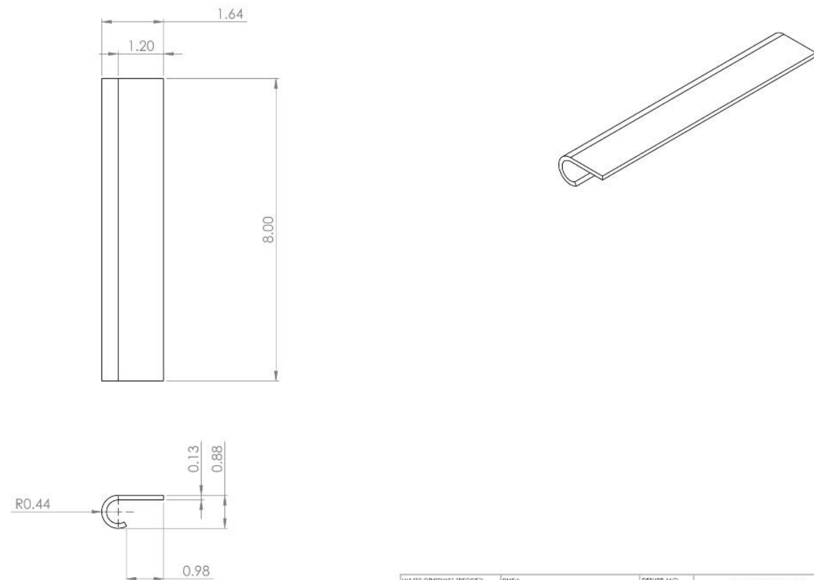

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MFG					
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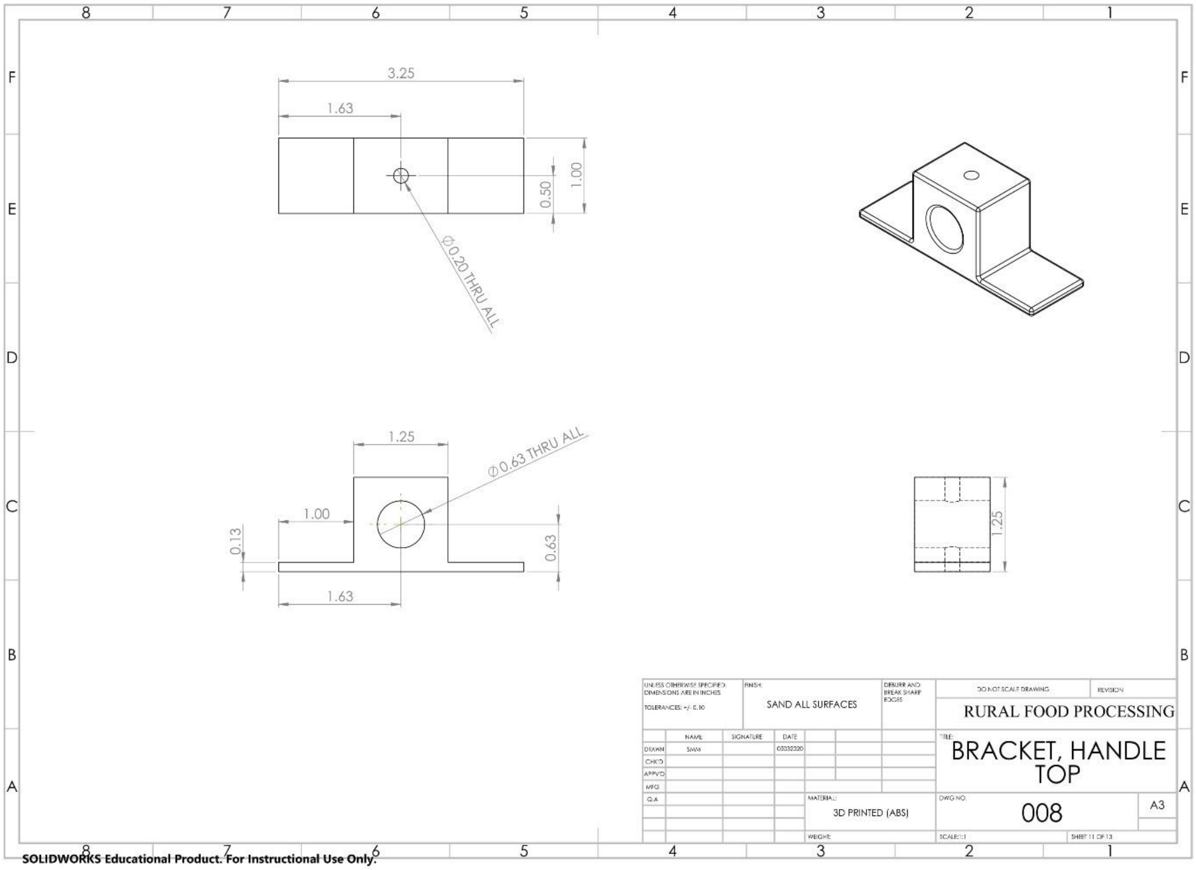
				WEIGHT:	SCALE:1:2 — SHEET 10 OF 13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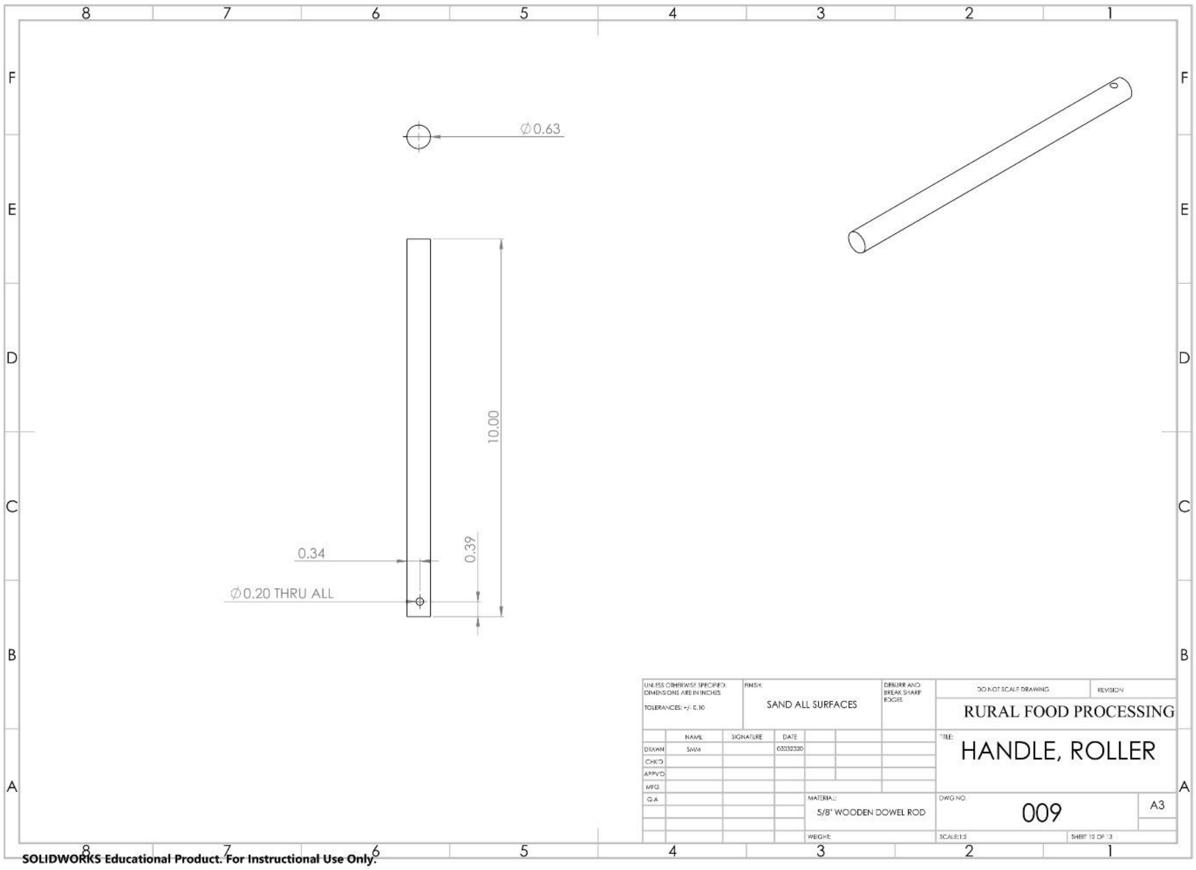
1.63
0.50
1.00
∅0.20 THRU ALL
1.25
∅0.63 THRU ALL
1.00
0.13
0.63
1.63
1.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES: +/- 0.10
FINISH:
SAND ALL SURFACES
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
RURAL FOOD PROCESSING
NAME
SIGNATURE
DATE
DRAWN
SAM
03032020
CHK'D
APPV'D
MFG
Q.A
TITLE:
BRACKET, HANDLE TOP
MATERIAL:
3D PRINTED (ABS)
DWG NO.
008
A3
WEIGHT:
SCALE:1:1
SHEET 11 OF 13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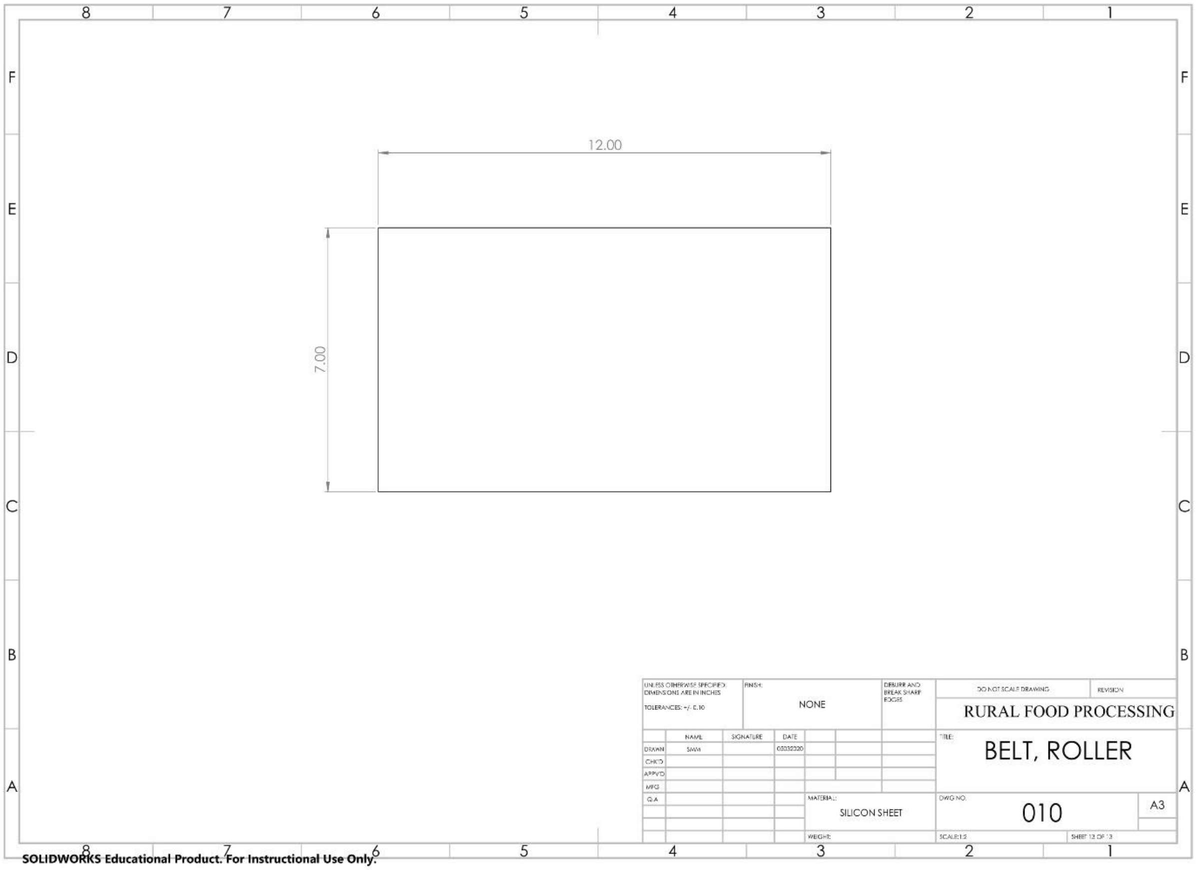
10.00
0.34
0.39
Ø0.20 THRU ALL
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES: +/- 0.10
FINISH:
SAND ALL SURFACES
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
RURAL FOOD PROCESSING
NAME
SIGNATURE
DATE
DRAWN
SAM
03032020
CHK'D
APPV'D
MFG
Q.A
TITLE:
HANDLE, ROLLER
MATERIAL:
5/8" WOODEN DOWEL ROD
DWG NO.
009
A3
WEIGHT:
SCALE:1:2
SHEET 12 OF 13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UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES
TOLERANCES: +/- 0.10
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DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
RURAL FOOD PROCESSING
NAME
SIGNATURE
DATE
DRAWN
SAM
CHK'D
APPV'D
MFG
Q.A
TITLE:
BELT, ROLLER
MATERIAL:
SILICON SHEET
DWG NO.
010
A3
WEIGHT:

Appendix D: Bill of Materials

Bill of Materials - Rural Food Processing

Team Cocoyam

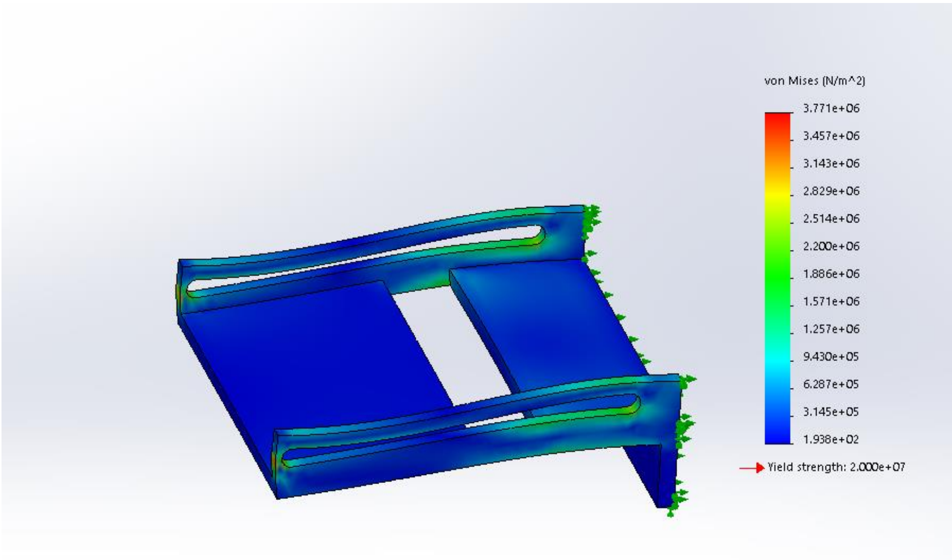
Part #	Part Name	Qty	Description	Functions	Material 1	Material 2	Dimensions (mm)	Cost 1	Cost 2
1	Reservoir	1	Reservoir	Hold cocoyam to be dispensed	3D Printed	Metal	280x200x200	$8.27	$67.58
2	Nozzle	1	Nozzle	Directs extruded cocoyam	3D Printed	Metal	50.68x90.68x106.35	$0.84	$7.45
3	Plunger	1	Plunger	Pushes cocoyam through reservoir into nozzle	3D Printed	Metal	193.65x193.65x283.18	$1.78	
4	Roller Base	1	Base, Roller	Base for all rolling operations	3D Printed	Metal	400x82.41x300	$4.55	-
5	Roller Handle	1	Handle, Roller	Provides grip to user to engage in rolling	3D Printed	Metal	250x15.88	$0.50	-
6	Handle Bottom Bracket	1	Bracket, Handle Bottom	Clamps belt to roller bar and provides mounting point for top bracket	3D Printed	Metal	200x41.11x22.23	$0.42	-
7	Roller Bar	1	Bar, Roller	Guides cocoyam through rolling process	3D Printed	Metal	400x15.88	$0.81	-
8	Belt	1	Belt	Provides shaping of cocoyam	Rubber Sheet	Rubber Sheet	200x300	$7.83	$7.83
9	Side Rail	2	Rail, Side	Guides roller bar through motion	3D Printed	Metal	400x46.35x56.35	$1.09	-
10	Belt End Bracket	1	Bracket, Belt End	Clamps end of belt to roller base	3D Printed	Metal	260x125x3.18	$0.71	-
11	Handle Top Bracket	1	Bracket, Handle Top	Connects handle to roller bar	3D Printed	Metal	33.18x70x20	$0.17	-
12	Handle Pin	1	Pin, Handle	Secures handle to top bracket	3D Printed	Metal	40x20	$0.04	-
13	90116A211	12	Screw, M4 x 0.7 mm	Fastener	COTS	COTS	M4 (14mm long)	$12.05	$12.05
14	94205A230	12	Nut, M4 x 0.7 mm	Fastener	COTS	COTS	M4 (5mm tall)	$5.49	$5.49
				Total Cost Estimate:				$44.54	$100.40

Note: Cost 2 has price for 90mx2m sheet, and 1219.2mm long rod which is sufficient for all parts

Sheet metal is also enough to make multiples of each part, meaning total cost overall would be lower

	Link to Cost estimate 1	Link to Cost estimate 2
1	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
2	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
3	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	https://www.steelsupplylp.com/sku/119871?gclid=EAIaIQobChMI_LDGmPbV5QIVchitBh0CGAtUEAQYBCA
4	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
5	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	https://www.steelsupplylp.com/sku/119871?gclid=EAIaIQobChMI_LDGmPbV5QIVchitBh0CGAtUEAQYBCA
6	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
7	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	https://www.steelsupplylp.com/sku/119871?gclid=EAIaIQobChMI_LDGmPbV5QIVchitBh0CGAtUEAQYBCA
8	https://www.grainger.com/product/E-JAMES-Neoprene-Rubber-Sheet-1MXC8	https://www.grainger.com/product/E-JAMES-Neoprene-Rubber-Sheet-1MXC8
9	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
10	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
11	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	African weld shop contact
12	($0.10 per gram) https://nau.edu/library/3d-design-and-scanning/	https://www.steelsupplylp.com/sku/119871?gclid=EAIaIQobChMI_LDGmPbV5QIVchitBh0CGAtUEAQYBCA
13	(50 per pack) https://www.mcmaster.com/90116a211	(50 per pack) https://www.mcmaster.com/90116a211
14	(50 per pack) https://www.mcmaster.com/94205a230	(50 per pack) https://www.mcmaster.com/94205a230

Appendix E: FEA



Appendix F: Durability test calculation

			Reactions		
			49.05	N	
			-98.1	N	
		units	49.05	N	
Total length	400	mm			
lenth in the x dir	393.9	mm			
length in x between supports	290	mm			
midpoint between supports	145	mm			
length in x between supports	0.29	m			
midpoint between supports	0.145	m			
base	300	mm			
height	10	mm			
I_no cut	25000	mm^4			
I@no cut	0.000000025	m^4			
height	10	mm			
base	100	mm			
I_@cut	8333.333333	mm^4			
I@ cut	8.33333E-09	m^4			
neutral axies	5	mm			
neutral axies	0.005	m			
length to start of cut	61	mm			
length to end of cut	85	mm			
length to end of cut, x-direction	83.70865901	mm			
length to end of cut, x-direction	0.083708659	m			
length from support to end of cut; x-dir	0.054788659	m			
Moment @cut	2.687383724	N*m			
Moment @ no cut	7.11225	Newton meters @	173.92 mm		
Bending stress @ no cut	1422450	pascal	N/m^2		
Bending stress @ cut	1612430.235	pascal	N/m^2		
	yiled strenght			yiled strenght	
plexiglass	64.8	Mpa	African Mahogany	6.9	Mpa
plexiglass	64800000	pa	African Mahogany	6900000	pa
check for failur due to bending	Does not fail			Does not fail	

Appendix G: Roller Bar Deflection Calculations

Material:	**PLA Plastic**					
E:	4.1	**Gpa**	4100000000	**Pa**		
l:	0.3	**m**				
a:	0.2	**m**				
Stock D:	(5/8")	(1/2")	(3/8")	(1/4")		
					(Units)	
D:	0.015875	0.0127	0.009525	0.00635	**(m)**	
I:	3.11763E-09	1.27698E-09	4.04045E-10	7.98114E-11	**(m^4)**	
F:	8.646	8.646	8.646	8.646	**(N)**	(5kgs @10deg)
ymax	-0.000620038	-0.001513764	-0.00478424	-0.024220216	**(m)**	
	-0.620037532	-1.513763506	-4.784240217	-24.2202161	**(mm)**	
F:	12.104	12.104	12.104	12.104	**(N)**	(7 kgs @10deg)
ymax	-0.000868024	-0.002119199	-0.006697715	-0.033907182	**(m)**	
	-0.868023859	-2.119198876	-6.697714965	-33.90718201	**(mm)**	
F:	15.563	15.563	15.563	15.563	**(N)**	(9kg @10deg)
ymax	-0.001116082	-0.002724809	-0.008611743	-0.043596949	**(m)**	
	-1.116081901	-2.724809328	-8.61174306	-43.59694924	**(mm)**	

Material:	**Wood**					
E:	9	**Gpa**	9000000000	**Pa**		
l:	0.3	**m**				
a:	0.2	**m**				
Stock D:	(5/8")	(1/2")	(3/8")	(1/4")		
					(Units)	
D:	0.015875	0.0127	0.009525	0.00635	**(m)**	
I:	3.11763E-09	1.27698E-09	4.04045E-10	7.98114E-11	**(m^4)**	
F:	8.646	8.646	8.646	8.646	**(N)**	(5kgs @10deg)
ymax	-0.000282462	-0.000689603	-0.002179487	-0.011033654	**(m)**	
	-0.282461542	-0.689603375	-2.17948721	-11.033654	**(mm)**	
F:	12.104	12.104	12.104	12.104	**(N)**	(7 kgs @10deg)
ymax	-0.000395433	-0.000965413	-0.003051181	-0.015446605	**(m)**	
	-0.395433092	-0.965412821	-3.051181262	-15.44660514	**(mm)**	
F:	15.563	15.563	15.563	15.563	**(N)**	(9kg @10deg)
ymax	-0.000508437	-0.001241302	-0.003923127	-0.019860832	**(m)**	
	-0.50843731	-1.241302027	-3.923127394	-19.86083243	**(mm)**	

		Deflections		
PLA Plastic				
	D1	D2	D3	D4
F1	0.62004	1.51376	4.78424	24.22022
F2	0.86802	2.11920	6.69771	33.90718
F3	1.11608	2.72481	8.61174	43.59695
Wood				
	D1	D2	D3	D4
F1	0.00028	0.00069	0.00218	0.01103
F2	0.00040	0.00097	0.00305	0.01545
F3	0.00051	0.00124	0.00392	0.01986

Appendix H: Roller Base Deflection Calculations

PLA Plastic			
4.1	**Gpa**	4100000000	**Pa**
0.13335	**m**		
(1/2")	(1/4")		
		(Units)	
0.015875	0.0127	**(m)**	
3.11763E-09	1.27698E-09	**(m^4)**	
1.1529441	1.1529441	**(N/m)**	(5kgs @10deg across *l*)
-3.56518E-06	-8.70406E-06	**(m)**	
-0.003565182	-0.008704057	**(mm)**	
1.6140684	1.6140684	**(N)**	(7 kgs @10deg across *l*)
-4.99109E-06	-1.21853E-05	**(m)**	
-0.004991089	-0.012185277	**(mm)**	
2.07532605	2.07532605	**(N)**	(9kg @10deg across *l*)
-6.41741E-06	-1.56675E-05	**(m)**	
-0.006417409	-0.015667503	**(mm)**	
Wood			
9	**Gpa**	9000000000	**Pa**
0.13335	**m**		
(1/2")	(1/4")		
		(Units)	
0.015875	0.0127	**(m)**	
3.11763E-09	1.27698E-09	**(m^4)**	
1.1529441	1.1529441	**(N/m)**	(5kgs @10deg across *l*)
-1.62414E-06	-3.96518E-06	**(m)**	
-0.001624138	-0.003965181	**(mm)**	
1.6140684	1.6140684	**(N)**	(7 kgs @10deg across *l*)
-2.27372E-06	-5.55107E-06	**(m)**	
-0.002273718	-0.00555107	**(mm)**	
2.07532605	2.07532605	**(N)**	(9kg @10deg across *l*)
-2.92349E-06	-7.13742E-06	**(m)**	
-0.002923486	-0.007137418	**(mm)**	

Deflections	
D1	D2
0.00357	0.00870
0.00499	0.01219
0.00642	0.01567
D1	D2
0.00162	0.00397
0.00227	0.00555
0.00292	0.00714

Appendix I: Force Requirement Calculations

Velocity (M/sec)	Force Required (N)	
	plexiglass	Wood
.0.1	1.128	2.368
0.2	1.214	2.448
0.3	1.357	2.580
0.4	1.555	2.763
0.5	1.809	2.999
0.6	2.119	3.286
0.7	2.485	3.625
0.8	2.907	4.016
0.9	3.385	4.459
1	3.918	4.954
1.1	4.508	5.500
1.2	5.154	6.099