Senior Design Fall 2016 Report

Cocoa Bean Winnowing Project
Joseph Barnes, Benjamin Jenkins, Montana Wells
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Introduction

The client for the Cocoa Bean Winnower Project is U. S. Roaster Corporation. U.S. Roaster Corp. is located in downtown Oklahoma City, OK and they specialize in the repair, manufacturing and design of coffee bean roasters for coffee producers. Their roasters range in capacity from 3 oz to 300 kg. While the roasters are designed to roast coffee, they are easily adapted to roast cocoa beans. Recently, several small scale gourmet chocolate producers have started using US Roaster Corp. roasters in the production of their product. The chocolate making process begins with roasting the cocoa beans. Once the beans are roasted they must be de-hulled, or winnowed. Winnowing separates the cocoa nib (the edible and sought after portion) from the outer hull. The cocoa nibs are then processed into chocolate or other cocoa products. The winnowing process in particular is important because if there is a high percentage of the husk present with the cocoa nibs, then the quality of the chocolate will be poor.

Currently in the industry there is not a small scale winnower that is both efficient and affordable for a small scale chocolate producers. US Roaster Corp. is interested in expanding their range of products to meet the needs of the gourmet chocolate industry.

Problem Statement

Triad Enterprises will research, design, and produce a winnower system that will be marketable to small scale chocolate producers.

Statement of Work
Scope of Work
The winnower must incorporate features and a price range that will make it marketable to small scale chocolate producers. US Roaster Corp. must be able to fabricate the majority of all the components of the winnowing system at their facilities with their current equipment. Aspects that are out of the scope of this project will be other components of chocolate production such as roasting, grinding, and tempering.

Deliverables
Triad Enterprises will deliver the following:

- A functioning cocoa bean winnowing system
- Marketable to small scale chocolate producers
- Primarily manufactured with stainless steel
- Provide easy access for cleaning of critical components
- Designed to be an unmanned operation
- Designed to be self-contained
- Produce minimal noise

Be powered by a standard wall outlet

Work Breakdown Structure

WBS 1.0  Hopper Design

1.1  Dimensions
1.2  Shape
1.3  Materials
   1.3.1  Lifespan
   1.3.2  Manufacturing requirements
1.4 Control System
   1.4.1 Low capacity alarm
   1.4.2 Automatic shutoff system

WBS 2.0 Initial Chaff Separating System

2.1* Choose Separating Option
   2.1.1 Roots Blower/ PD Pump style rollers
   2.1.2 Reciprocating Crusher Plate
   2.1.2 Conveyor Mesh Crushing Screen
   2.1.3 Rotary Impact
   2.1.4 Rubber Belt Shearing

WBS 3.0 Chaff and Nib Sorting System

3.1 Pneumatic Separation
   3.1.1 Method of separation
      3.1.1.1 Cyclone
      3.1.1.2 Air blast
      3.1.1.3 Constant flow
   3.1.2 Required air velocity
      3.1.2.1 Determine Terminal Velocity Thresholds
   3.1.3 Fan/vacuum specification
   3.1.4 Materials
3.1.4.1 Lifespan
3.1.4.2 Manufacturing requirements

3.1.5 Control Systems
3.1.5.1 Shutoff mechanism

3.2 Vibratory sifting
3.2.1 Sifter
3.2.1.1 Sifter mesh size

3.2.2 Vibration mechanism
3.2.2.1 Vibration rate/displacement
3.2.2.2 Durability of material/components being vibrated

3.2.3 Stages of sifting
3.2.3.1 Number of necessary screens
3.2.3.2 Desired/attainable sieve size necessary

3.2.4 Materials
3.2.4.1 Lifespan
3.2.4.2 Manufacturing requirements

3.3 Integration of sorting systems
3.3.1 Determine to what extent each method of sort will be used
3.3.2 Determine integration parameters

WBS 4.0 Conveyance Methods
4.1 Conveyors

4.1.1 Type of conveyors

4.1.2 Material of the conveyors

4.1.3 Power system for the conveyors

WBS 5.0 Systems Integration

5.1 Integrate all sensors of the components together

5.2 Ensure all convenience systems are compatible

5.3 Install integrated controls interface

WBS 6.0 Physical Properties

6.1 Range of variability of cocoa beans

6.1.1 Weight

6.1.2 Density

6.1.3 Size

6.1.4 Shape

6.1.5 Volume

6.2 Properties of cocoa bean chaff

6.2.1 What affects how it clings to the cocoa nib?

6.2.2 What affects how the chaff fractures?

WBS 7.0 Documentation

7.1 Specifications
7.1.1 List design specifications and drawings for each component
7.1.2 List of materials needed

7.2 Research
7.2.1 Physical properties of cocoa beans
7.2.2 How roasting affects the physical properties of cocoa beans
7.2.3 Existing methods of how to winnow cocoa beans
7.2.4 Existing cocoa bean winnowers in the market
7.2.5 Existing patents relevant to cocoa bean winnowing
7.2.6 Food safety requirements for the winnowing system

7.3 Budget
7.3.1 Cost of travel
7.3.2 Cost of prototype
    7.3.2.1 Material cost
    7.3.2.2 Design cost
7.3.3 Cost of testing samples
7.3.4 Cost of testing experiments

7.4 Planning
7.4.1 Milestones for design process
7.4.2 Gantt chart
7.4.3 Task list

7.4.4 Work Breakdown Structure

7.4.5 Dates for field trips

7.4.6 Dates for testing

7.5 Presentation and Report material

7.5.1 Fall presentation material

7.5.2 Fall final report draft

7.5.3 Fall final report

**WBS 8.0 Engineering Review and Approval**

8.1 Review and approve engineering

8.1.1 Evaluation meeting

8.1.2 Troubleshooting
8.1.3 Design review

8.2 Verify design meets client’s parameters and expectation

8.3 Approve Final Design

8.3.1 Finalization Review Meeting

**Task List**

**Fall 2016**
1) Start initial test on conceptual cocoa bean cracking methods-(Thursday Nov. 3)
2) Complete Project Proposal-(Friday Nov. 4 by 5:30pm)
3) Submit Preliminary Design Concepts-(Monday Nov. 7)
4) Present Preliminary Design Concepts-(Friday Nov. 11)
5) Finalize Technical Literature Review and Research-(Tuesday Nov. 15)
6) Finalize Fall Semester Design Review Presentation-(Friday Nov. 18)
7) Finish Analyzing Faculty and Client Feedback-(Wednesday Nov. 23)
8) Complete Fall Design Report Draft-(Friday Nov. 25)
9) Finalize Fall Semester Design Report Draft-(Wednesday Nov. 30)
10) Initiate Tests on Conceptual Cocoa Nib Sorting Methods-(Thursday Dec. 1)

Spring 2017

1.) Complete Testing on Conceptual Cocoa Bean Cracking Methods-( Friday Jan. 20th)
2.) Complete Testing on Conceptual Cocoa Nib Sorting Methods-(Friday Jan. 27th)
3.) Complete Control Systems Design-(Friday February 3rd)
4.) Complete Power/Utility Requirements for the Winnower Design- (Wednesday February 8th)
5.) Complete Expected Prototype Cost Analysis-(Friday February 17th)
6.) Finalize Winnower Design and Receive client approval-(Wednesday February 22nd)
7.) Finalize Drafting all Necessary Parts Diagrams-(Friday March 3rd)
8.) Order All Necessary Material and Components for Prototype-(Wednesday March 8th)
9.) Begin Fabrication/Assembly of Prototype-(Monday March 20th)
10.) Complete Prototype Assembly-(Wednesday April 5th)
11.) Complete Prototype Troubleshooting-(Friday April 14th)
12.) Complete Spring Final Report Draft-(Friday April 21st)
13.) Complete Final Presentation-(Friday April 28th)
14.) Complete Final Spring Design Report-(Friday April 28th)
15.) Final Senior Design Presentation-(Friday May 5th)
Technical Analysis

Patents

Patents that deal with the winnowing process of cocoa bean manufacturing are not greatly available. Several patents were found that are related to the winnowing process.

**Method for Producing Fat and/or Solids from Cocoa Beans (2000)**
Patent #6015913

This patent goes farther into the cocoa bean manufacturing process than the scope of our project requires our team to go. The patent discusses a method of processing cocoa beans for producing solids from fat-containing products. They go into the cocoa bean process as a whole, and include some of the winnowing process.

**Method and Apparatus for Separating Lighter and Heavier Portions of Threshold Tobacco (1977)**
Patent #4045334

This patent gives the method and an apparatus that separates lighter and heavier parts of threshold tobacco by creating two adjacent vortices which circulate in opposing directions. The turbulence of the vortices causes the separation by combining to form a rising column of high-velocity air which carries off the lighter material while the heavier portions drop down. A similar approach could be used to separate the hulls from the nibs.

Technical Literature Review

**Semi-Theoretical Analyses on Mechanical Performance of Flexible-Belt Shearing Extrusion Walnut Shell Crushing.** (Lui, 2016)

The article analyzes a specific walnut cracking process and the theoretical calculation for it. Aspects of this process could be modified to better suit
cocoa winnowing. The flexible belt process is as follows; “First, the walnut is broken to a certain extent by extrusion and shearing between the upper extrusion roller and the supporting plate. Then, rubbing, extrusion, and shearing of the walnuts with two working belts--the upper working belt at a higher speed and lower working belt at a lower speed--simultaneously ensures effective breakage and protects the walnut meat. The height of the upper and lower extrusion rollers is adjustable. In this way, the space between the two working belts in the rubbing area and the wedge-shaped angle can be adjusted effectively to fit all sizes of walnuts.” A critical difference in the cracking process between walnuts and cocoa beans is that walnuts have much thicker and harder shells. Cocoa beans will not need as strenuous process to crack/separate the shaft from the nib.

**Chocolate Alchemy Winnowing Forums**

Several forums are available for people researching on how to process and produce chocolate products. There are specifically 39 different forums related to the cracking and winnowing process for cocoa beans. Topics range from issues in trying to manufacture small scale DIY winnowers to troubleshooting winnower systems.

**Design Concepts towards Cocoa Winnowing Mechanization for Nibs Production in Manufacturing Industries** (Akinnuili, 2015)

This article gives detailed design descriptions as well as theoretical mathematical models for many of the components of the cocoa bean winnowing process. The best description of their bean crushing utilizes gravity to crack the beans onto a vibratory tray and a blower to recycle the beans back into a “crushing chamber”. The design details include the actual designs for some mechanical components such as the frame, the hopper, and auger lifting system. The estimated cost of the materials for the components, the required system assembly, and the final cost of the possible designs are also included.
Market Research

**Aether Winnower:**
A vacuum winnower that also cracks the bean. The cracking utilizes a juicer with the juice screen removed, but the blades and housing is recognized as a wear item. The vacuum is a shop vacuum and is not contained within the unit itself. Costs $1800 without champion juicer or 6.5hp vacuum.

*Figure 1.1* A photo of the Aether Winnower equipped with champion juicer
**Bear BWI:**

**Table 1.1** Specifications of Bear BWI winnowers

<table>
<thead>
<tr>
<th>Specifications</th>
<th>BWI 500</th>
<th>BWI 1.500</th>
<th>BWI 3.000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity [kg/h]:</td>
<td>ca. 500</td>
<td>ca 1.500</td>
<td>ca. 3.000</td>
</tr>
<tr>
<td>Electrical power[kW]:</td>
<td>7</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>Air consumption [m³/h]:</td>
<td>2900</td>
<td>3600</td>
<td>4900</td>
</tr>
<tr>
<td>Dimensions [m]:</td>
<td>2.6x2.7x4</td>
<td>6.8x2.7x5.6</td>
<td>5.8x3x6.5</td>
</tr>
<tr>
<td>Loss nibs</td>
<td>.15-.25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shell content in nibs</td>
<td>&lt;1.75%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This system cracks and winnows the beans using both screens and vacuum. The machine is large enough that an elevator is required to lift the beans up and into the hopper. The scale of this machine is much larger than what would be appropriate for the scale of this project.

**Figure 1.2** A photo of the industrial size Bear BWI Winnower

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**Vortex Winnower:**

**Table 1.2** Specifications of Vortex winnower

<table>
<thead>
<tr>
<th>Specifications</th>
<th>single</th>
<th>double</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footprint [in]:</td>
<td>49x16</td>
<td>49x16</td>
</tr>
<tr>
<td>Winnowing speed (Variable) [kg/h]:</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Cracker Feeder/vacuum [V]:</td>
<td>110/110</td>
<td>110/110</td>
</tr>
<tr>
<td>Cracker Feeder/vacuum [amps]:</td>
<td>4/9</td>
<td>4/18</td>
</tr>
<tr>
<td>Nib loss</td>
<td>0.25%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Shell Content in Nibs</td>
<td>0.20%</td>
<td>0.20%</td>
</tr>
</tbody>
</table>
This machine simply winnows the chaff from the nibs using a cyclone vacuum system. The machine has a pending patent for their process and does not appear to be as robust as other designs. Again, the vacuum is a separate unit and is not included in the machine itself.

**Figure 1.3** A photo of the Vortex Winnower

**Winn-150:**

**Table 1.3** Specifications of Winn-150 winnower

<table>
<thead>
<tr>
<th>Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity [lbs/hr]:</td>
<td>330</td>
</tr>
<tr>
<td>Footprint [ft]:</td>
<td>5x12</td>
</tr>
<tr>
<td>Materials</td>
<td>Stainless Steel</td>
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</table>

This winnower is all inclusive, both cracking and winnowing. It is a very through process utilizing a screen rake, vacuum, and vibration. The machine also sucks the beans up and into their cracking system. The machine layout is very spacious and takes up a good deal of floor space.

**Delani CAC-101-WIN:**

*Awaiting response from manufacturer for more information

**Figure 1.4** A photo of the industrial Delani CAC-101-WIN
Sunrise DX-400:

Table 1.4 Specifications of DX-400 winnower

<table>
<thead>
<tr>
<th>Specifications</th>
<th>100-400</th>
<th>2.2</th>
<th>0.75</th>
<th>1.05x0.9x1.55</th>
<th>140</th>
<th>304 SS</th>
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</thead>
<tbody>
<tr>
<td>Capacity [kg/h]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power [kW]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fan Power [kW]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensions [m]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight [kg]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This winnower both cracks the beans and separates them using only air velocity. It is all inclusive and has a wide range of capacity. It costs between $10,000 and $100,000 depending on order size and if you purchase other equipment as well.
Testing

Temperature Testing
An apparatus was made to test the effectiveness of impact on cocoa beans under various conditions. The apparatus was constructed using 2x4 piece of wood 24 inches long with a weight of approximately 1lb per 12 inches and hinged on one end. This devise allowed us a consistent and repeatable crushing of the cocoa beans to simulate a crushing force. This was used to test four variations of cocoa beans: dry cocoa beans, wet cocoa beans, dry cocoa beans frozen in liquid nitrogen, and wet cocoa beans frozen in liquid nitrogen. After beans were impacted, they were then sieved through a screen whose voids measured 3.5mm diagonally and the small and large particles were weighed separately. It was hoped that freezing would take advantage of the differences in physical properties between the cocoa nib and hull. It was determined that freezing made little effect on final particle size after impacting. It was also determined that cocoa beans become soaked rapidly, negating the need for an increased soaking period.

Impact Testing
Another devise has been constructed utilizing a squirrel cage fan as the basis. The blade were removed and impact paddles have been added. The Motor turns at a speed of 1600 rpm and the diameter of the rotating assembly is 5in. Without varying the motor’s speed, an impact speed of 34.88 ft/sec was achieved. Initial testing has shown that there is insufficient spacing between the impacting paddles to allow the beans to fall low enough past the top edge of the paddle to get an honest impact. To solve this problem, the number of paddles will either decrease and/or the motor’s speed will need to be reduced. If these strategies prove to not be successful, it may be necessary to increase the diameter of the rotating assembly. Once a large enough gap between impacting paddles has been developed, velocities that yield good separation will further be tested by varying the
impacting speed and possibly the inclination of the impacting paddles with respect to the rotating axis.

Environmental, Societal & Global Impacts

The areas of sustainability that this project will impact include the economic, environmental, and socioeconomic impact to the gourmet chocolate industry. US Roaster Corp prides itself on the high quality of their equipment that rarely needs to be serviced. Building a machine that will withstand the rigors of constant usage is essential to this project. Cocoa products are growing in demand each year, especially products from small bean-to-bar producers. Therefore, from an economic standpoint the winnower will be a good investment for US Roaster Corp. Bean-to-bar chocolate producers care where their chocolate is sourced from, often choosing organic and fair-trade cocoa beans. Consciously sourcing cocoa beans not only looks good for their brand, it is better for the environment and for the many cocoa bean growers around the world, many of which are in third-world countries. By enabling small bean-to-bar chocolate producers to more efficiently make chocolate, our product should have a positive impact on the environment and socioeconomic status of many cocoa bean farmers around the world.
Engineering Specifications

- Winnow at a rate of 100 lbs/hr
- Winnow at an efficiency >95%
- Not allow greater than 2% shell in the final nib output
- Retail price near $3000
- Be powered by either 120V or 240V AC
- Not exceed 90 dB of sound
- Minimize moving parts
- Be aesthetically pleasing
- Be easy to clean

Freshman Teams

Two freshmen teams were assigned to work in conjunction on this project, with each group having five members. Tasks were delegated to the freshman groups that would assist in the development of the project and allow them to be introduced to the engineering design process. The freshmen were required to complete the given task, write a report over the task, and prepare and present a poster.

Team 1
Team 1’s task was to determine a viable air velocity range to separate the hull and the nib of the cocoa beans. To complete this task, the freshmen utilized the air velocity separator in the BAE lab. They determined that the best sort was achieved at around 5 m/s, shown in Figure 2.1.
Team 2
Team 2’s task was to design a hopper that meets the given specifications: the hopper must hold 100 lbs of roasted cocoa beans, determine appropriate food grade material, not exceed a loading height of 5 ft, and must minimize the surface area while maintaining the proper volume. The freshmen must also make a model of hopper utilizing CAD software, seen in Figure 2.2. The final task for team 2 was to contact material suppliers and estimate a price of the hopper.

Table 2.1 Cone hopper dimensions

| Cone | | | | |
|---|---|---|---|
| Radius (ft) | Height (ft) | Volume (ft³) | Surface Area (ft²) |
| 1.20 | 2.40 | 3.01 | 14.63 |
| 1.10 | 2.60 | 2.99 | 13.55 |
| 1.00 | 2.90 | 3.04 | 12.77 |
| 0.90 | 3.10 | 2.92 | 11.67 |

Table 2.2 Rectangular hopper dimensions

| Rectangle | |
|---|---|---|---|---|
| Height (ft) | Width (ft) | Length (ft) | Volume (ft³) | Surface Area (ft²) |
| 1.02 | 1.70 | 1.80 | 3.12 | 13.26 |
| 1.01 | 1.90 | 1.60 | 3.08 | 13.17 |
| 0.98 | 1.40 | 2.10 | 2.88 | 12.74 |
| 1.03 | 2.20 | 1.40 | 3.16 | 13.55 |
Figure 2.2 Proposed hopper design
**General Design Concepts**

**Hopper**

*Figure 3.1* A sketch of the shape of the hopper concept

Clogging was anticipated at the base of the hopper, and was observed at Izzard Chocolate during a site visit, so a simple roller to agitate the clogged area was conceived.

*Figure 3.2* A sketch of an agitating roller at the outlet of the hopper concept

*Figure 3.3* A side view sketch of another agitator concept with paddles

Tendency of the beans to slide on the simple roller required a redesign of the base of the hopper. A paddled wheel was conceived that would no only prevent clogging of the beans, but also allow adjustable and predictable delivery rate of the beans from the hopper.

*Figure 3.4* A sketch highlighting the curved edges to prevent binding of the paddles with beans
A more common and possibly cheaper method to feed beans out of the hopper is an auger, typically vertical in orientation. A horizontal orientation would not only be easier to drive, but help keep overall height to a minimum.

**Cracking Method**

Much like US Roaster Corp’s current roller grinders, cracking the cocoa beans with a roller grinder would be a simple and achievable design. To mitigate
the beans from not passing through the round rollers, lobed rollers were thought of as an alternative to smooth roller grinders.

Upon observation, quick impact was seen as an effective way of cracking the beans. A paddle wheel that rotates and impacts the beans would also be independent of individual bean size. The axis of rotation of the wheel in the first draft was horizontal, which is perpendicular to the flow of beans. To ensure consistent contact impact velocity, it was thought to feed the beans down in parallel with the rotating axis.

**High Risk Design**
Figure 5.1 A modeled representation of the vertical impact wheel

Figure 5.2 The preliminary model of the impact wheel with hopper and chute

This design is appropriately named because it is high risk. No other winnower on the market uses this approach and it has yet to be thoroughly tested. The main cracking method is impact with the paddles on a wheel traveling with high angular velocity. Some pros of this design include: the cracker is indiscriminant of bean size, the velocity adjustable to vary impact force and a simple design and construction. Some cons of this design include: unproven and untested design, loss of contact with bean and requires metered feed out of hopper.

Low Risk Design

Figure 5.3 A modeled representation of the concept rollers

Figure 5.4 Modeled concept rollers with hopper and connecting chute

This is the low risk design. It is a conceptually common design utilizing a two stage roller-cracker design which homogenizes the crushed bean size. The cocoa beans would be crushed between the roller and the wall of the housing. A lobed roller from the conceptual designs could be utilized. The roller-cracker is similar to US Roaster Corp’s current coffee roller-grinders, so fabrication would not be difficult. Some pros of this design include: robust and adjustable, guarantees beans that have passed through will be cracked/crushed and self-metering flow of beans out of the hopper. Some
cons of this design include: tolerance and part intensive, potentially less differentiable qualities between nib and hull and finer particles will require a more thorough separation process.

Project Schedule
<table>
<thead>
<tr>
<th>Day</th>
<th>Start</th>
<th>Finish</th>
<th>Duration</th>
<th>Task Name</th>
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<td>11/06</td>
<td>11/17</td>
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<td>Design, Draft All Necessary Parts Plans</td>
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<td>Finalize Window/Door and Receive Client Approval</td>
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<td>11/26</td>
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<td>3 days</td>
<td>Determine Concept/Prototype Cost Analysis</td>
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<td>11/27</td>
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<td>3 days</td>
<td>Control Systems Design</td>
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<td>11/28</td>
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<td>Testing on Conceptual Cocoa Nut Sorting Methods</td>
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<td>11/31</td>
<td>12/03</td>
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<td>12/06</td>
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<td>Present/Communicate Design Concepts</td>
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<td>12/07</td>
<td>4 days</td>
<td>Develop Preliminary Design Concepts</td>
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<td>Market Research, Trip, Izard Chocolate</td>
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<td>12/09</td>
<td>4 days</td>
<td>Technical Literature Review &amp; Analysis</td>
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<tr>
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<td>12/08</td>
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<td>4 days</td>
<td>Meet Client U. S. Input, Corporation</td>
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<tr>
<td>3</td>
<td>12/09</td>
<td>12/11</td>
<td>4 days</td>
<td>Develop Team Organization &amp; Structure</td>
</tr>
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</table>

**Figure 6.1 Gantt Chart Tasks**
Figure 6.2 Gantt Chart
Proposed Budget

After consulting with the client, Dan Jolliff, about his expected costs for this endeavor, he voiced his wishes to keep our testing and concept construction near his expected retail price. His aim is to market these winnowers to the small volume chocolatiers with a price tag in the range of $3000 - $4500. What is needed in the construction is roughly estimated in the table below. After concluding the testing and determining the plan of action with regards to the high-risk or low-risk design, a much more detailed and accurate description of our budget will be developed.

Table 6.1 An estimated budget breakdown

<table>
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<tr>
<th>Item</th>
<th>Percent Budget</th>
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<tbody>
<tr>
<td>Electric motor(s)</td>
<td>12</td>
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<tr>
<td>Frame material</td>
<td>15</td>
</tr>
<tr>
<td>Stainless sheet</td>
<td>17</td>
</tr>
<tr>
<td>Drive belts</td>
<td>5</td>
</tr>
<tr>
<td>Bearings</td>
<td>2</td>
</tr>
<tr>
<td>Electrical cords</td>
<td>2</td>
</tr>
<tr>
<td>Electrical controllers</td>
<td>8</td>
</tr>
<tr>
<td>Fans</td>
<td>5</td>
</tr>
<tr>
<td>Vacuum</td>
<td>13</td>
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<tr>
<td>Wire mesh</td>
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<td>Fabrication</td>
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<td>Testing</td>
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