Amaranth Grain Seed Cleaner Development and Testing

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This thesis titled
Amaranth Grain Seed Cleaner Development and Testing

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ABSTRACT

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Amaranth Grain Seed Cleaner Development and Testing

Director of Thesis: Gregory G. Kremer

This thesis presents the development and testing of a prototype amaranth grain seed cleaner. This research was conducted to develop a cleaning solution for amaranth grain that was ridden with organic and inorganic debris. The prototype device employed a conveyor belt system using velvet fabric as a friction material to take advantage of surface texture differences between grain and debris particles. Device operating parameter adjustments included feed rate, conveyor belt speed, and conveyor deck incline angle, all of which impacted cleaning performance. Cleaning performance was determined by analysis of measured seed loss and measured separated debris. Deck angle settings provided the largest impact on cleaning performance, contributing to 51% of overall seed loss results and 45% of overall separated debris results. Total debris composition ranged from 8.4% to 10.2% by weight. Across all operational parameter settings the conveyor cleaner separated 88% of all debris with 0.8% seed loss.
This work is dedicated to the hard working folks at Shagbark Seed & Mill and everyone
that is working in sustainable, small scale agriculture around the world.
ACKNOWLEDGMENTS

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CHAPTER I: INTRODUCTION

Background

The general topic of seed processing is a wide spread area of interest in the food industry. For any seed handling process, whether it is cleaning, separating and sorting, or conditioning for further processing steps, there are time and cost penalties for inefficiency at any level. Seed processing at the smaller scale must consider more strict physical and financial constraints.

Numerous small scale cleaning techniques have been proposed and established. Cleaning and/or separating operations attempt to differentiate and segregate unwanted debris from good product. Unwanted debris can arise from numerous sources including harvesting techniques, soil composition, and farming environment. Unwanted debris can include inedible particles such as insects (dead or alive), animal matter, soil and rocks, trash, and fungal matter, as well as undesirable particles such as pieces of leaves, plant stems, immature seeds, empty or rotten seed shells, dust, and sand (Farran & Macmillan, 1979) (United States Department of Agriculture, 2006) (Akinoso, Olayanju, Hassan, & Ajiboshin, 2010).

Beginning in the 1970’s amaranth has been researched heavily for its remarkable nutritional make-up (Venskutonis & Kraujalis, Nutritional Components of Amaranth Seeds and Vegetables: A Review on Composition, Properties, and Uses, 2013). Findings led to results showing how amaranth grain added to human diets can provide numerous health benefits in ways that are unattainable by most other grains. Grobelnik states that amaranth grain has the “highest amount of protein ... more fiber, and 5 to 20 times the
content of calcium and iron” compared to all other grains (Grobelnik, Turinek, Jakop, & Bavec, 2010). Additionally, the oil found in amaranth seeds contain anti-inflammatories which may help reduce LDL-cholesterol (Grobelnik, Turinek, Jakop, & Bavec, 2010) (Venskutonis & Kraujalis, Nutritional Components of Amaranth Seeds and Vegetables: A Review on Composition, Properties, and Uses, 2013). Amaranth oil also contains relatively high amounts of squalene, oil which is widely used in dermatology products for its anti-oxidant, anti-histaminic, anti-biotic, anti-allergenic, and anti-carcinogenic properties (Tjan) (Gamel, Mesallam, Damir, Shekib, & Linssen, 2007). Amaranth oil contains 2.26%-5.57% squalene. For comparison, shark liver oil and olive oil which are two popularly published sources of squalene oil contain 65-85% and 0.4-0.8% squalene, respectively (Venskutonis & Kraujalis, Nutritional Components of Amaranth Seeds and Vegetables: A Review on Composition, Properties, and Uses, 2013) (Tjan).

The highly nutritious properties of amaranth encourage the grain to be used to help alleviate malnutrition in low-income communities where food access is limited (Kunyanga, Imungi, Okoth, Vadivel, & Biesalski, 2012). As a food source, both the leaves and seeds of the crop can be eaten providing an energy dense meal additive.

Project Partner

Shagbark Seed & Mill is a growing company that strives to provide access to healthy food for local community members. The company is proud of their “Food-to-Table” mission of working with small farmers to maintain Ohio grown and produced, non-GMO (genetically modified organisms) food products. Shagbark Seed & Mill’s vision:
“To be a model for regionally based production, processing, and marketing of grains, beans, nuts, flour, and oil seed that focuses on fair farm and worker wages, great flavor and nutrition, and equitable distribution through schools, retailers, farmers markets, restaurants, bakeries, and community and school yard gardens.” (Mill).

Shagbark Seed & Mill got started with grants to establish high nutrition test plots on local farms. These high nutrition products included quinoa, amaranth, millet, buckwheat, corn, and several varieties of beans. The products on these test plots became extremely attractive to a broad market. With pre-orders and further interest the experimental testing expanded into a business. Currently Shagbark Seed & Mill specialized in grain, and legume products including flours, pastas, crackers, and chips. Amaranth processing has been a challenge for the company due to the specialized equipment required to effectively clean the grains from unwanted debris. Amaranth products prove to play a key role in Shagbark Seed & Mill’s mission due to its high nutritional value and ability to be locally grown.

As far as grain processing, Shagbark uses an air-screen cleaner, which will be explained later, to clean various grains and legumes in their factory. Shagbark employees have attempted to run as-harvested amaranth grain through their air-screen cleaner with marginal success. As-harvested amaranth contains a variety of large and small particles, some of which is able to be separated out via the clipper cleaner. It is the small and similarly sized particles which the clipper cleaner is ineffective at separating. A device that could exploit characteristics of the debris in order to separate them from the amaranth grain would serve Shagbark’s operation of cleaning amaranth.
Objectives

Shagbark’s background along with literature reviews has been synthesized to form the following objectives of this thesis.

1. Develop a friction based amaranth grain cleaning method using upholstery velvet as the friction material. Prototype cleaning methods must be applicable to a working model that conforms to specifications as per Table 1, the Design Specifications table.

2. Conduct testing of the prototype amaranth seed cleaner to demonstrate seed cleaning performance both qualitatively and quantitatively as described in Methods Section.

3. Compare experimental cleaning performance with product requirements based on cleaning performance found in literature.
CHAPTER II: LITERATURE REVIEW

Research Methods and Approach

Research began with becoming a member of the American Society of Agricultural and Biological Engineers and searching their online technical library including journal articles and meeting proceedings. The ASABE technical library was a great starting point with a broad collection of information related to grain handling. I also became a member of the Amaranth Institute and attended their international conference in Chicago, IL, alongside employees from Shagbark Seed & Mill. The conference exposed us to numerous experts in the field including manufacturers, researchers, producers, growers, breeders, business owners, and marketers of amaranth. The conference was invaluable in uncovering further importance of amaranth as a food source and what an impact it can make in the health and wellbeing of those involved with it. Additional sources were gathered, with help of the engineering librarian, Megan Tomeo, using Alden Library’s Engineering Village, Agricola, and Food Science Source databases.

Research has been found that covers mid to small-scale cleaning of seeds, grains, and legumes. Designs of grain cleaning machinery vary depending upon the grain parameter of which a machine separates good product from unwanted debris. Practically this means grains are separated based on one or several physical properties. These properties were reported from Akinoso and Bracacescu and can include aerodynamic properties (drag coefficient and terminal velocity), density, shape, size, surface texture (coefficient of friction), weight, and magnetic properties (Akinoso, Olayanju, Hassan, &
Seed Cleaning Devices

One type of device called an air-screen cleaner, is widely studied for cleaning applications due to their adaptability for many sizes of grain. Air-screen cleaners rely primarily on particle size and aerodynamic properties of grain and debris to achieve separation. The first stage of handling is composed of multi-screen system. The first of the screens prohibits particles larger than that of the good product from proceeding yet allow the good product and smaller particles to continue. A second, fine meshed screen, allows for very small particles to fall through, into a trash bin, but catch the good product and similar sized particles. This final mixture may contain immature seeds, hollow seeds, rotten seed shells, and small pieces of plant material. The final step in the air-screen cleaner is to pass the final mixture of good product and similar sized particles through or into an air-channel, blowing either vertical or horizontal, and is calibrated to blow off any particles which are of lighter weight than the good product. An example of this technique, presented by R. Akinoso, was used in an experimental machine designed to clean sesame seed at reported flow rates up to 200 kg/h at 98.7% efficiency (Akinoso, Olayanju, Hassan, & Ajiboshin, 2010). To handle this amount of grain, Akinoso’s machine was operated by a single 3.75 kW motor at 700 rpm with a foot print of just 1.2 square meters at a height of 1.5 meters (Akinoso, Olayanju, Hassan, & Ajiboshin, 2010). Figure 1 shows a schematic of an air screen separator’s internal functions and the path of particulate flow.
Figure 1. Shows a cross section view of an air screen separator, illustrating the path of material as it is separated.

In Figure 1, Red lines indicate path of large particles that are separated by the first screen, called out by line number 4. Orange lines indicate fine debris particles that pass through both the course screen and the fine screen, called out by line number 5. Blue lines indicate the path of particles similar in size as good grain but are separated in the air channel provided by the fan, called out by line number 12. Green lines indicate the path of successfully separated good grain.
Another type of seed cleaning machinery that cleans grains on the basis of grain size or density is called a gravity separator or gravity table. These devices consist of a vibrating, perforated table, that is angled slightly with respect to horizontal both longitudinally and laterally, on which the grain mixture is introduced. Perforations in the table bed allow for forced air to be blown up into the grain/debris mixture. This aerated mixture, when vibrated, forms distinct layers of material with less dense particles “floating” to the top layer while denser materials “sink” to the bottom, according to Harmond (Harmond, Brandenburg, & Klein, 1968). This phenomenon lets less dense matter on the top layer to gradually fall to the lower end of the table opposed to the denser matter is “walked” along the surface of the table, upwards, to the higher end of the table (Harmond, Brandenburg, & Klein, 1968). The general gravity table operation can be visualized in Figure 2.
Figure 2. Shows movement of material across the deck of a gravity table separator. [14]

In Figure 2, for each representative triangular area, material flow is from the top right to the bottom left. The center scenario is under proper operating conditions, where it can be seen that layers of material (heavy and light) can be differentiated and can be separately collected at the end of the table. Each palate around the outside of the circle represents a snapshot of the deck under various operating parameters in order to show potential deficiencies in operation parameters. Bracacescu and Harmond reported that the tables’ adjustments of tilt, oscillating direction and amplitude, and blower speed are
interrelated and can be adjusted to alter the separation performance for various seed mixtures (Bracacescu, Pirna, Popescu, & Stan, 2012) (Harmond, Brandenburg, & Klein, 1968).

Another category of machines achieve grain/debris separation based on surface texture and seed shape. Harmond presents two such devices; the velvet roller and the inclined draper separator. The inclined draper is a more simple design, with one major design feature being a textured conveyor belt at an adjustable tilt angle. Figure 3, below shows a model of an inclined draper cleaner.

![Figure 3. Schematic of the cleaning mode of an inclined draper cleaning device.](image-url)
The inclined draper provides separation based on both surface texture and shape. Specifically, shape of an object as it pertains to its ability to roll. The conveyor belt allows for round and smooth seed to be pulled downward by gravity along the deck surface into a collecting bin while rough and flat seed is carried upwards into a separate collecting bin. In the case of Shagbark’s amaranth which is composed of a mixture of good seed, immature seed, rotten seed, and seed casing or chaff, both ability to roll and surface texture will provide two plausible means of separation.

The velvet roller also achieves separation based on surface texture and ability to roll. The velvet roller is composed of two inclined, velvet covered drums, in contact about their long edge. These two drums rotate in opposite directions, creating a regressing V-shaped trough about their length. Figure 4 shows a diagram of some of the key design components of a velvet roller cleaning machine.
Figure 4. Schematic and cross sectional view of a velvet roller cleaner.

A grain/debris mixture is fed from the upper end of the rollers and is fed directly into the trough. As the mixture works its way down the trough, rough particles are caught by the velvet and carried out of the trough, to be collected along the sides of the rollers. Smooth particles are able to slide along the center of the trough and collected at the end of the rollers. Harmond claims the velvet rollers’ function to be relatively simple when in operation and allow for continuous operation with “little attention” (Harmond, Brandenburg, & Klein, 1968). Operation parameters such as feed rate, roller incline angle, roller dimensions, and roller rpm affect cleaning performance and must be adjusted one at a time to accurately observe the changes in separation.
Both the inclined draper and the velvet roller employ separating methods that match the cleaning requirements of Shagbark Seed & Mill’s amaranth. That is, as a final cleaning process that separates good seed from similarly sized rotten seed as well as similar sized chaffy plant matter. Research states that similarly sized particles are difficult to separate using other cleaning methods since no one physical seed characteristic can be exploited to clean all debris (Farran & Macmillan, 1979). Both rotten seeds and chaff are either non-uniform in shape or rough edged. These characteristics show potential for a cleaning process that takes advantage of the rough texture of the unwanted debris.
CHAPTER III: METHODS

Design Criterion

Collaboration with Shagbark Seed & Mill aided in the selection of key design specifications. An amaranth cleaner built specifically for Shagbark was designed with cleaning performance and machine reliability as focus targets. Additional machine requirements and targets are listed in Table 1, below.

Table 1

*Design specifications for the prototype amaranth grain seed cleaner*

<table>
<thead>
<tr>
<th>Specification Statement</th>
<th>Units</th>
<th>Marginal Value</th>
<th>Ideal Value</th>
<th>Explanation of specification &amp; target values</th>
<th>Verification method (including # of trials if testing)</th>
</tr>
</thead>
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<tr>
<td>Handle desired flow rate of amaranth</td>
<td>lb./hr.</td>
<td>50</td>
<td>100</td>
<td>Chosen for compact machine size and operation time constraints</td>
<td>Based off of experimental testing. Extreme operating conditions must also be tested to ensure continuous operation.</td>
</tr>
<tr>
<td>Grain separation performance</td>
<td>% clean</td>
<td>95</td>
<td>98.5</td>
<td>Must achieve cleanliness produced by other marketable cleaning devices.</td>
<td>Regularly test samples for % cleanliness during operation</td>
</tr>
<tr>
<td>Operate on 110V outlet</td>
<td>Yes/no</td>
<td>Yes</td>
<td>No</td>
<td>220V requirement should be avoided if possible</td>
<td></td>
</tr>
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Additional qualitative design features were considered such as:

- Ease of portability: Via forklift if necessary or by human power with an ideal value of no more than 4 persons on flat ground and shallow inclines.
- Minimize # of operators: Cleaning performance should be visible and operational settings should be adjustable by a single operator.

- Extreme operating conditions: Large fluxes in feed rate or excessive debris should not cause clogging or jamming of the device in any way.

Design of Experiments

*Modes of Operation and Validating Data*

Data will be taken at varying operating parameter settings. Operating parameters to be adjusted include amaranth grain feed rate, conveyor deck angle, and conveyor speed. The deck angle setting primarily affects separation performance by utilizing differences in a particle shape and thus its ability to roll. Also affecting cleaning performance is particle surface texture. At varying deck angles, frictional forces will change due to changes in normal forces between grain and debris particles and the conveyor belt. It is the differences in particles shape and surface texture of grain vs. debris that will allow a friction based cleaner to achieve particle separation.

Amaranth grain flow rate settings and conveyor speed settings must be calibrated to maximize debris separation while minimizing seed loss. A high and a low value will be tested for all three machine parameters. Figure 5, below shows the operating parameter matrix that will be used to determine the most effective operating parameter setting. The matrix shown in Figure 5 will be replicated again, only substituting “Low Feed Rate” for the high feed rate setting. Combined, the two operating parameter matrices will produce a total of eight unique operational configurations to be tested.
Figure 5. A matrix showing the operational parameter configurations to be tested.

Seed loss and separated debris measurements will be determined at each operational parameter configuration by taking the average from five separate and independent cleaning trials. This procedure will produce a total of forty cleaning trials that will provide data used for discussion. The order of the eight operational configurations will be randomized. The randomized order will be done to eliminate any cleaning bias that should arise due to the running time of the machine. Factors that could go unseen and alter cleaning performance may include: changes in belt tension, wear of velvet fabric, and debris accumulation on velvet surfaces. Between cleaning trails, the conveyor will be allowed to run until the deck is free of all grain and debris. Following all cleaning trials the cleaning brush and velvet belt will be inspected for wear or changes.
in belt and cleaning brush operation. Alterations will be addressed and documented before cleaning trials continue.

Seed loss and separated debris will correspond to the weight of each material component that will be collected after an amaranth grain mixture is sent through the cleaning device. Weights will be found by a digital scale with a resolution of 0.01 lbs.

Testing Apparatus Development

The first friction based cleaner design that was created resembled the velvet roller design. This device, shown in Figure 6, was intended to provide a visual display of the velvet’s properties and its interaction with the amaranth grain.

*Figure 6. The velvet roller model.*
To display the cleaning effect, grain/debris mixture was introduced into the trough, created between the two rollers. The two rollers were then turned by hand in opposing directions. As the rollers were turned grain would continue to travel downward in the trough and debris was easily carried out of the trough and onto the floor. This was the first evidence of the potential of velvet as the frictional material to be used for further testing.

Limitations of the velvet roller design were immediately made evident. The first of these was the issue of feed rate. Desired machine capabilities were benchmarked by the design specifications from Table 1. The nature of the design of the velvet roller utilizes only a single line where velvet is in contact with grain and debris. Because of this design, the flow rate must be quite small for a single set of rollers. Flow rate could be increased if additional rollers were set up in parallel formation. Additionally, rollers could be set up in series that could potentially produce various grades of cleanliness as material went from one set of rollers to another. A challenge that came from the velvet roller model was a challenge for a design that could increase feed rates.

Another result from observations of the velvet roller was that cleaning performance was heavily dependent on particle size. Smaller objects, regardless of shape and surface texture, could sit lower in the trough and would have a more difficult time being caught by the velvet and carried upwards. This was problematic because some of the debris that was mixed in with the grain is of similar size as the good amaranth grain. Particle shape was another contributing factor to cleaning performance. Long slender
objects would have a tendency to align themselves in the direction of the roller axis and thus sit low in the trough, and have a hard time being separated out.

The combined qualitative results of the velvet roller suggested that another approach be sought to provide adequate cleaning performance. The development of the testing apparatus proceeded through several iterations to achieve the final system used for testing. Initially, an experimental velvet coated, vibrating, inclined seed cleaner was used to evaluate cleaning potential of as-harvested amaranth. The device employed a stationary, vibrating deck surface to achieve gravity driven particle movement. Figure 7 shows the experimental setup.

The vibrator cleaner was developed in an attempt to simulate some of the working functions as the velvet roller but in a way that increases the working area and thus increase material flow rate. The working surface was set at an incline of 18 degrees. Manual feed rate was measured to be 70 lbs/hr. Five runs through the vibrator cleaner was effective in cleaning approximately 66% of the total debris with negligible seed loss. This separated debris accumulated over the 5 runs and can be seen in Figure 8, below.

The vibrator cleaner was shaken using a small part tumbler strapped to the velvet covered deck with thick bands of rubber. This apparatus was created as part of the verification of the theory of a friction based cleaner. The vibrator cleaner was intended to display differences in frictional properties between grain and debris particles. This device successfully showed large enough differences in frictional properties, affirming that a more advanced friction based cleaner should be designed. This more advanced design would allow for various machine settings to be tested in order to find ideal operational
parameters. The testing apparatus that would be used for data collection utilized a velvet fabric covered conveyor belt opposed to a stationary deck.

Figure 7. The experimental vibrating velvet cleaner.
Figure 8. Fine scalpings successfully separated using the inclined vibrating velvet cleaner. Debris consists of immature seed, fine plant material, dust, rotten seed, and slender shaped plant stems.

The device was not effective in cleaning larger debris such as heavy weight woody pieces, stones or dirt clods. Figure 9 shows the leftover debris that was not successfully separated by the vibrator cleaner.
Figure 9. Course debris which failed to be separated by the inclined vibrating velvet cleaner.

When running the vibrator cleaner with amaranth that has already been through the air-screen cleaner the results showed a more refined product. Figure 10 shows the fine scalpings separated out of the pre-cleaned amaranth. Separated material from the pre-cleaned amaranth is similar in composition to that of the as-harvested amaranth except with additional seed loss.
Figure 10. Separated chaff from amaranth grain and debris that has been previously cleaned using an air-screen separator.

Recall these large particles are however able to be separated with the air-screen clipper cleaner. Vibrations through the working deck caused amaranth to diverge into the middle of the velvet deck causing pileups. This landslide effect is seen in Figure 11.
Figure 11. Amaranth grain falling down the inclined vibrating velvet deck. The dark spot near the center of the deck shows a gathering of fine debris particles.

The vibrator cleaner successfully showed improved feed rates over the velvet roller design. Also, some material such as small, slender shaped debris that was missed by the velvet roller design was fully separated out. The vibrator cleaner brought forth the concern of belt cleanliness and the accumulation of debris on the velvet over the course
of cleaning trials. This result added to design ideas for the maintenance of the conveyor cleaner and provide additional discussion points on material selection for future work.

The vibrator cleaner is similar in function to the gravity table. The key difference in the vibrator cleaner is the absence of forced air blowing through the working deck. Like the gravity table, the working deck is subject to an oscillation and set at a certain incline. Very consistent separation patterns were seen in the vibrator cleaner. During most trials, material would migrate toward the center of the working deck. Furthermore, as seen in Figure 11, not only amaranth grain would converge together but debris particles, especially very fine particles would migrate towards each other to form, distinguished patches of material about the working deck.

Use of a tumbler as means of vibrating the working deck has placed limitations on quantifying cleaning performance. Oscillation amplitude and direction are difficult to measure and possibly not consistent. The addition of a measurable vibrator would add much to the testing parameters and would allow for reliable data to be collected.

The observed landslide effect caused amaranth grain to push debris down the incline that would otherwise be caught in the velvet. If the mode of feeding the amaranth grain onto the working surface were more precise, it would improve cleaning performance and testing consistency.

The experimental setup of the conveyor cleaner employed a modified electronically controlled exercise treadmill. The robust design of a treadmill is equipped with a powerful electric motor and intended to operate for long periods at a time under a substantial load. This gave assurance to the longevity of all moving parts. The treadmill’s
digital readout for running speed was useful to quickly adjust conveyor speed. However this readout was used only as a reference. Conveyor speed was manually measured and recorded in ft./min for more accurate data. The treadmill was equipped with a pneumatic deck incline piston. This was especially useful in preliminary trials when deck angle settings were being determined because of the easily repeatable deck angle adjustments. Figure 12 shows the treadmill in position for cleaning trials.

Also shown in Figure 12 is the bulk materials hopper that stored and fed amaranth grain onto the conveyor deck. The hopper was suspended from a fixture attached to a large structural I-beam of the garage. By suspending the hopper it saved time by eliminating the need to build a separate stand to support the hopper. The idea of attaching the hopper to the frame of the conveyor was also discarded for several reasons. The conveyor belt and treadmill frame were under constant modification and service for much of the preliminary cleaning trials so from a machine maintenance perspective attaching the hopper to the treadmill would yield an additional component to remove if the treadmill was in need of repair (often meaning turning the treadmill on its sides to access componentry). Additionally, the treadmill frame was not stationary. During cleaning the deck of the treadmill was moved to a high deck angle or low deck angle depending on the operational parameter settings per cleaning trial. It was undesirable for the pitch of the hopper to change, even just a few degrees. In early stages of hopper testing, it was observed that at low pitch angles, amaranth grain would freely fall out of the hopper’s exit chute. This is controlled by a material property of the grain/debris mixture called the angle of repose. The angle of repose is the steepest angle that a pile of a granular material
can make before material on the slope face begins to slide. This angle was not measured for the amaranth/debris mixture but, visually, was slightly less than thirty degrees. Hopper pitch angle was set so that angle of repose did not affect feed rate and so that grain/debris flow rate was solely controlled by the designed feed system in place.

During preliminary cleaning trials the conveyor was not fitted with the wooden splash guard shown in Figure 12. This setup resulted in the grain/debris mixture having downward momentum and much material, both grain and debris, was ending up in the grain bin at the bottom end of the conveyor. This downward momentum was an overpowering factor, compared to cleaning performance differences due to changes in deck angle, feed rate, and conveyor speed settings. After these poor results the hopper was turned 180° so that the exit chute of the feed hopper was at an angle of about 80° with the conveyor deck. As grain left the feed hopper chute, its downward trajectory would then make a near perpendicular angle of impact with the conveyor deck. This was an improvement over the initial setup and allowed for the operational parameter settings to control cleaning performance.

Further improvements were made that improved cleaning performance over any combination of operational parameter settings. As grain and debris fall out of the feed hopper chute and impact the conveyor belt, material is spread over the width of the deck. There was a concentration of material at the center of the belt. The addition of the wooden splash guard provided an additional impact and additional time for grain and debris to spread to the full width of the conveyor belt. This even distribution of grain and debris on the conveyor belt resulted in more consistent cleaning performance. Now, in
this new scenario, grain and debris interact less with each other as they are on the surface of the conveyor belt. Grain and debris are now either pulled downward by gravity or are carried upwards by the friction from the velvet fabric. There is less influence on grain being pulled upwards by debris travelling upwards and likewise, debris being pulled downwards from falling grain. More discussion on observations of this will be included in the discussion section.

Grain flow rate was achieved with an electric powered auger. The auger’s custom design, shown in Figure 13 was made from heavy gauge wire wrapped around a post to create a very coarse screw design. Auger design was chosen based on requirements to successfully feed a wide range of particle sizes and shapes. This design was small enough to pull amaranth into the feed chute and the large spaces between ‘threads’ allowed room for large woody particles to fall into and be carried along. The auger was powered by a small electric motor with an attached gear reduction box. Preliminary testing showed best feeding results with slow auger RPMs. Using a DC power source, motor voltage was adjustable between pre-determined values of 1.7 volts to 3.2 volts. An aluminum coupler was designed and machined to fix the keyed motor shaft to the custom auger shaft. Figure 14 shows the electric motor, gear reduction box, and motor coupler.
Figure 12. The conveyor cleaner and feed hopper in position for cleaning trials.
Figure 13. Feed auger positioned at the base of the feed hopper exit chute.

Figure 14. Electric motor, gear reduction box, and aluminum motor coupler.
The factory equipped running belt of the treadmill measured 13.9 inches wide by 97 inches long. This running belt was beneficial to use as a base for the velvet because it added significant strength and rigidity to the belt system. The entire running belt was covered with a synthetic velvet fabric material. Two major iterations of fabric fixture to the running belt were tried. The final design used regal style paper clip and is shown in Figure 15, below.

![Figure 15](image)

**Figure 15.** (at left) Belt retention clips installed. (top right) Retention clips bending around conveyor rollers. (bottom right) Regal style paper clips.

During preliminary cleaning trials the treadmill running belt was covered with a stretchy velvet fabric. This fabric was sewn together to be 4” shorter than the total length of the running belt. The elasticity of the fabric easily stretched this amount and remained in a slightly tensioned state during cleaning trials. This effect showed to provide good
cleaning performance because the velvet fabric would remain flat against the running belt and not produce wrinkles that would disturb cleaning dynamics. The stretch velvet eventually failed at its seam after approximately eleven hours of run time. Seam failure is shown in Figure 16.

*Figure 16. Seam failure of the elastic velvet fabric.*

The stretch velvet was a very lightweight fabric. Even though the fabric was never under a heavy load, the constant bending and stretching was too much abuse. The thin profile of the stretch velvet was very helpful because the seam where the fabric was sewn did not produce a large trough or any kind of bulge for material to fall into or be bounced off of. The stretch velvet was replaced with a nonstretch velvet that was used for final cleaning trials. The non-stretch velvet was a heavier weight fabric than the stretch velvet.
and almost every seam design resulted in a small raised section that would potentially disrupt cleaning performance. Much time was spent testing different seam designs to find a best solution. Seam design iterations are shown in Figures 17, 18, and 19. Extra reinforcing stitching and a flexible fabric adhesive resulted in very high strength seams. These designs were eventually discarded because of the excess material present which caused too much of a hump on the surface of the conveyor belt. A traditional flat seam was selected because of its low profile. This type of seam has only one row of stitching on the backside of the fabric and thus is not an extremely robust seam. Given the heavy weight of the nonstretch velvet, the belt was sure to last much longer than the lifespan of the stretch velvet.

![Flat seam design](image)

**Figure 17.** Flat seam design. Providing lowest profile seam and chosen for final belt design.
Figure 18. Once-folded seam design with reinforced stitching. This design increases strength but at the cost of a larger height profile.

Figure 19. Heavily reinforced seam. Very high strength seam but lacks the flexibility to fold around conveyor rollers.
The conveyor cleaner was fitted with a belt cleaning device. A large painters brush was fastened to the underside of the conveyor providing continuous removal of debris from the belt. Debris that was ejected from the brush was collected and added to the debris bin for final cleaning performance measurements. The belt cleaning brush is shown in Figure 20, below.

![Conveyor belt cleaning brush.](image)

**Figure 20. Conveyor belt cleaning brush.**

Grain and debris collection equipment were vitally important components of the testing apparatus. Much care was taken to eliminate loss of seed before, during and after cleaning trials. The first place this becomes an issue is when the grain/debris mixture leaves the feed hopper and comes in contact with the deck of the treadmill. A wooden splash guard was installed onto the frame of the treadmill at an angle of 60° to the
conveyor belt. In preliminary cleaning trials grain was seen bouncing off of this splash guard, away from the conveyor belt, and onto the floor. Thick paper was used to create sides and a top to eliminate this. Paper was used because it was constantly being used and adapted, moved, or trimmed to achieve the ideal shape and size to catch all material. These parts are seen in Figure 21, below.

*Figure 21. Grain being fed at a low feed rate, displaying the distribution of particles across the conveyor belt’s width.*
Also seen in Figure 21 are white plastic rails along the sides of the conveyor belt. These are the factory sides to the treadmill though they have been turned 180° so that the taller, steeper side provides the boundary for the grain to move about the velvet surface. These side rails serve a dual purpose. Not only do they contain the grain and debris as it travels about the conveyor deck but it also provides protection for the retention clips. In Figure 15, which shows the belt with the side rails removed, it can be seen that the side edges of the velvet material appear darker; this is the section of the velvet that is fastened to the factory installed running belt and covered by the side rails, being kept cleaner than the rest of the working surface.

Installed about half way down from the top of the conveyor belt a plastic shield, termed the velocity reducer. This component was added after observing behavior of grain and debris as they are put through a cleaning trial. Similar to grain and debris interactions that were explained with the inclusion of the wooden splash guard, the velocity reducer did not interfere with test parameter settings but rather improved cleaning performance across all operational setting configurations. For the case of most debris, it was observed that if a particle that exited the hopper chute and impacted the conveyor deck was not immediately separated and carried upwards into the debris container, it would fall all the way down the conveyor surface into the grain bin. It seemed that the downward momentum was too great compared to the upward force generated by the friction of the velvet fabric. The inclusion of the velocity reducer stopped this downward momentum and allowed for the velvet fabric to do its job and carry unwanted debris particles
upwards into the debris container. Thankfully, the mature grain, though slowed down, continued to travel downwards into the grain bin.

The velocity reducer was made from 1/8 inch thick plastic sheet. The geometry was developed by heating the plastic and bending it to the desired shape. A detailed photo and installed photo can be seen in Figure 22.

*Figure 22.* Velocity damper and raised side rails.
At the bottom end of the conveyor cleaner, more heavy weight paper guides were installed to direct all falling material into the grain bin, below. Figure 23 shows these guides in action with a screenshot from video footage of a cleaning trail. Grain can be seen following the guides towards the back plate where it then falls straight down into the grain container.

![Figure 23. Grain guides at the bottom end of the conveyor belt.](image)

The exact design and material selection of the grain catchment components are not critical to their function. Overall, material catchment was achieved using these various splash guards along the top, sides, and bottom of the conveyor cleaner to contain material to only the conveyor deck, grain bin, or debris bin. Collection bins were placed at the upper and lower ends of the conveyor to catch debris and amaranth grain,
respectively. Additionally, large poster board was placed underneath the working area. This would catch falling debris or grain should it leave the conveyor surface. This excess catchment was never a measureable amount.

**Testing Procedures**

Starting values for deck angle and conveyor speed will be set, using visual assessment of when grain separation is achieved and lost. This process will be used to determine a “high” and a “low” setting for deck angle and conveyor speed.

The as-harvested amaranth/debris mixture inherently has a trace amount of fine dust mixed in with it. This dust may collect within the velvet fabric, affecting cleaning performance. Before cleaning trials are conducted the amaranth grain cleaning device must be run for several minutes to achieve steady state cleaning. This run time is to ensure that the velvet belt will have the same amount of possible debris buildup (presumably mostly fine dust) for the first measured runs as it will for the last runs.

Amaranth grain feed rate settings will be selected using the marginal and ideal values as listed in Table 1. Deck angle settings will be established by finding the upper and lower limits of dynamic friction between the deck and grains and debris, respectively. The low deck angle will be found by increasing the deck angle from horizontal and stopping at the point when amaranth grain freely falls downward. This process will be done at a very slow conveyor speed with the sole intention of eliminating static friction. This process will be done a second time with focus on when the majority of debris begins to freely fall downward.
The high and low conveyor speed settings will be found by first setting the deck angle to the average of the high and low setting. The low conveyor speed will be found by monitoring and increasing the conveyor speed until the introduction of the amaranth grain mixture onto the conveyor deck no longer piles up, creating a mound of grain. The high conveyor speed setting will be established by increasing the conveyor speed until grain separation becomes violent, ejecting grain and debris materials into the air. All material must be in contact with the deck surface for proper separation.

Two grades of amaranth grain were considered for assessing cleaning performance of the friction based cleaner. Shagbark Seed & Mill was able to provide ‘as harvested’ amaranth which is directly out of the harvesting equipment. Shagbark attempted to clean their amaranth grain with an air-screen separator, resulting in a cleaner product. This cleaning process was able to separate out much of the extremely fine particles like dust and small pieces of organic matter and also the very large woody particles. Figure 24, below shows a comparison of the as-harvested next to the pre-cleaned amaranth.
Figure 24. As-harvested grain (left) and air-screen cleaned grain (right).

For purposes of Shagbark, tests could have been carried out on air-screen cleaned amaranth knowing that they already have the ability to take care of some cleaning using their equipment. However in an attempt to test the friction based cleaner under the most adverse conditions, the as-harvested amaranth grain will be used for all cleaning trials. Along with potentially allowing Shagbark to eliminate a cleaning step and still end up with marketable grain, data from the as-harvested amaranth cleaning will be more applicable to a wider audience. Other cleaning operations around the world may have similar debris such as the large woody pieces and fine dust that would not be tested if cleaning trials were to be conducted on the air-screen cleaned amaranth.
It was estimated that about 200 pounds of as-harvested material would be required to complete all cleaning trails. Only about 150 pounds were available. To provide the remaining weight, a measured half of the results of a cleaning trial were remixed with as-harvested amaranth and used for future cleaning trials. Discussion on the possible adverse effects of this will be explained in later chapters.

To start a cleaning trail, the deck angle was set to the appropriate height. The conveyor was turned on and set to the high or low setting depending on the trial. The conveyor was allowed to run for about a minute to ensure a clean velvet surface. At the same time, the DC power source that controlled feed rate was turned on and a timer was started. Cleaning trails were ran for about 40 minutes at high feed rates and about 75 minutes at low feed rates to clean nearly the same amount of material during an individual cleaning trial. At the end of the allotted time, the DC power source was turned off and the timer was stopped. After a cleaning trail both the upper container and lower container were weighed. Using the elapsed time, and total weight, feed rate was calculated. The upper container was subject to further analysis. This container which consisted of mostly debris with minor seed loss was poured through several sieves to filter the debris and seed by size. Once everything larger than amaranth grain was separated, the leftover material consisting of good seed, rotten or immature seeds, and debris that was similar in size as amaranth grain was sent through the conveyor cleaner, with manual feed rate to remove all remaining debris. After this final cleaning, good seed and all debris were fully separated and a seed loss value and separated debris value could
be accurately measured. At this stage, half of the good grain and half of the debris were remixed and combined with additional as-harvested material for the next cleaning trial.
CHAPTER IV: RESULTS

The data presented in this chapter are the results of cleaning trials using the conveyor cleaner. Discussion of these results will continue in the following chapter.

Conveyor Cleaner Results

The operating parameter matrix from Figure 5 produced eight unique operational parameter configurations. These eight settings are shown in Table 2, below.

Table 2

*Operational Parameter Settings*

<table>
<thead>
<tr>
<th>Operational Parameter Settings</th>
<th>Deck Angle</th>
<th>Conveyor Speed</th>
<th>Feed Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting HHH</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Setting LHH</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Setting HHL</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Setting LHL</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Setting HLH</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Setting LLH</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Setting HLL</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Setting LLL</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>
Table 3 lists the quantitative values that were used for deck angle, conveyor speed, and feed rate. All values were chosen based off preliminary cleaning trials and visual analysis of cleaning performance. These values were then used for final cleaning trials where seed loss and separated debris quantities were measured.

Table 3

*Operational Parameter Setting Values*

<table>
<thead>
<tr>
<th></th>
<th>High Setting Value</th>
<th>Low Setting Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Angle (degrees)</td>
<td>30</td>
<td>28.5</td>
</tr>
<tr>
<td>Conveyor Speed (in/sec)</td>
<td>19</td>
<td>10.3</td>
</tr>
<tr>
<td>Feed Rate (lb/hr)</td>
<td>9.9</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Seed loss and separated debris were measured values using a digital scale. These values are shown in Table 4, below. Also shown in Table 4 is a Feed Hopper Throughput value. This was the cumulative mass of the grain/debris mixture that was fed for all five cleaning trials for a single operational parameter configuration. The actual mass of grain/debris separated varied trial to trial due to the total time of the cleaning trial. These differences were eliminated by creating a unique Weight Factor for each operational configuration to effectively normalize the results of all cleaning trials to a common 25.7 lb. of material (the average sum for each set of five cleaning trials). These corrected data values along with the Weight Factor are shown in Table 5. This normalized data made for easier graphical representation of the cleaning performance. Table 6 shows average
values of feed hopper throughput, seed loss, and separated debris along with standard deviation of the five replicate trials of each setting.

Table 4

*Feed Hopper Throughput, Seed Loss, Separated Debris Values*

<table>
<thead>
<tr>
<th>Setting</th>
<th>Total Feed Hopper Throughput (lb)</th>
<th>Total Seed Loss (lb)</th>
<th>Total Separated Debris (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHH</td>
<td>31.34</td>
<td>0.15</td>
<td>2.38</td>
</tr>
<tr>
<td>LHH</td>
<td>29.33</td>
<td>0.35</td>
<td>2.46</td>
</tr>
<tr>
<td>HHL</td>
<td>21.01</td>
<td>0.06</td>
<td>1.68</td>
</tr>
<tr>
<td>LHL</td>
<td>22.59</td>
<td>0.23</td>
<td>1.96</td>
</tr>
<tr>
<td>HLH</td>
<td>33.65</td>
<td>0.24</td>
<td>2.53</td>
</tr>
<tr>
<td>LLH</td>
<td>22.47</td>
<td>0.51</td>
<td>1.96</td>
</tr>
<tr>
<td>HLL</td>
<td>23.78</td>
<td>0.14</td>
<td>1.92</td>
</tr>
<tr>
<td>LLL</td>
<td>21.37</td>
<td>0.22</td>
<td>1.84</td>
</tr>
</tbody>
</table>
Table 5

_Corrected Values of Feed Hopper Throughput, Seed Loss, and Separated Debris_

<table>
<thead>
<tr>
<th>Setting</th>
<th>Weight Factor</th>
<th>Feed Hopper Throughput (lb)</th>
<th>Seed Loss (lb)</th>
<th>Separated Debris (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting HHH</td>
<td>0.82</td>
<td>25.7</td>
<td>0.12</td>
<td>1.95</td>
</tr>
<tr>
<td>Setting LHH</td>
<td>0.88</td>
<td>25.7</td>
<td>0.31</td>
<td>2.15</td>
</tr>
<tr>
<td>Setting HHL</td>
<td>1.22</td>
<td>25.7</td>
<td>0.07</td>
<td>2.05</td>
</tr>
<tr>
<td>Setting LHL</td>
<td>1.14</td>
<td>25.7</td>
<td>0.26</td>
<td>2.23</td>
</tr>
<tr>
<td>Setting HLH</td>
<td>0.76</td>
<td>25.7</td>
<td>0.18</td>
<td>1.93</td>
</tr>
<tr>
<td>Setting LLH</td>
<td>1.14</td>
<td>25.7</td>
<td>0.58</td>
<td>2.24</td>
</tr>
<tr>
<td>Setting HLL</td>
<td>1.08</td>
<td>25.7</td>
<td>0.15</td>
<td>2.07</td>
</tr>
<tr>
<td>Setting LLL</td>
<td>1.2</td>
<td>25.7</td>
<td>0.26</td>
<td>2.21</td>
</tr>
</tbody>
</table>
Table 6

*Average Values of Feed Hopper Throughput, Seed Loss, and Separated Debris*

<table>
<thead>
<tr>
<th>Setting</th>
<th>Mean Feed Hopper Throughput (lb)</th>
<th>Seed Loss (lb)</th>
<th>Separated Debris (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Value</td>
<td>Standard Deviation</td>
<td>Mean Value</td>
</tr>
<tr>
<td>HHH</td>
<td>5.14</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>LHH</td>
<td>5.14</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>HHL</td>
<td>5.14</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>LHL</td>
<td>5.14</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>HLH</td>
<td>5.14</td>
<td>0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>LLH</td>
<td>5.14</td>
<td>0.15</td>
<td>0.05</td>
</tr>
<tr>
<td>HLL</td>
<td>5.14</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>LLL</td>
<td>5.14</td>
<td>0.05</td>
<td>0.01</td>
</tr>
</tbody>
</table>

The operating parameter with the most degree of uncertainty was the feed rate measurement. Feed rate measurements were calculated using the time during which the electric auger was powered and total weighed material at the end of a cleaning trial. Therefore, feed rate data refers to total fed amaranth/debris mixture and not only separated grain weight fed. Chauvenet’s criterion was applied to determine if there were any erroneous data points or outliers in the feed rate measurements, and one data point was removed. Tables 4 and 5 present values that are representative of the remaining 39 cleaning trials.
Deck angle settings were adjusted by way of raising and lowering the bottom treadmill support using a shim. This provided a repeatable change in deck angle setting for every trial and errors were negligible. Conveyor speed was adjusted using the factory installed digital readout on the treadmill’s controller. The MPH reading using the treadmill’s digital readout and was manually measured in in/sec to achieve a more accurate conveyor speed reading. Further discussion will be presented on effects of conveyor speed in the discussion section.

A visual representation of the cleaning performance of the conveyor cleaner can be seen in Figure 25. This picture shows the separated debris next to the grain that it was originally mixed in with.

*Figure 25. Volume comparison of fully separated debris next to clean grain that it was mixed in with.*
CHAPTER V: DISCUSSION

Testing Procedures

Mixing procedures as described were carefully analyzed. The decision to run cleaning trials using a partial mixture of grain/debris that had already been subject to a cleaning trial was done out of necessity and with best judgment. It can be certain that the same quantity of debris existed in the previously cleaned mixture by using weighed amounts of grain and debris. The question that naturally arose by following this procedure was if material properties of the grain and debris particles were changed in any way that could affect cleaning performance.

Experimental observations could suggest that three properties of the grain/debris mixture could be subject to change due to this conditioning of the particles.

First is the removal of unmeasurable debris. This primarily refers to dust that exists in the as-harvested material. During a cleaning trial some of this dust is removed. Dust is ejected into the air as material is dumped into the feed hopper and also when material exits the feed hopper chute and impacts the conveyor deck. Though the dust was very visible it was also unlikely that the presence of dust interfered with cleaning performance. Prior to cleaning trials it was a concern that dust would accumulate on the conveyor surface and pack up the velvet fabric however this occurred much less than anticipated.

The second material property change that may take place is the alteration of the size of debris particles. This change would come from the interaction of grain and debris particles with each other as well as with the velvet fabric. Changes in size could come
from the breakage of debris particles. All material, both grain and debris are very dry. Pieces of dry organic matter such as small plant stems, pieces of plant leaves, or dirt clods have the potential to break into smaller pieces during a cleaning trail. This change could occur in two locations throughout a cleaning trial. One is in the feed hopper as material is working its way down toward the exit chute. A second is on the conveyor deck when material strikes the conveyor deck and also as material is in a turbulent state, travelling either upwards or downward on the conveyor deck.

Third, there is the potential for a particle’s surface texture to change during a cleaning trial due to a polishing action. Similar to the risk of particle breakage, the polishing action would likely occur in the feed hopper as well as on the conveyor deck. This polishing action could knock off small sharp edges that exist on debris particles, making them a generally smoother particle. Recall that the use of velvet fabric takes advantage of these rough surface features. Changes in surface texture may be the most likely to alter cleaning performance.

The method of mixing previously separated grain and debris in with 100% as-harvested material began several cleaning trials before data acquisition started. This helped with the assurance that the previously separated and as-harvested mixture has reached a state where material properties were changing as little as possible. Refer to Figure 26 for a visual representation of the mixing procedure.
Figure 26 shows how the half of the material in the feed hopper that is composed of previously separated material is ever changing. This figure starts from a mixture of pure 100% as-harvested material. As this process continued, the half of the mixture which is composed of previously separated material slowly gets closer and closer to a steady state of material properties. Data acquisition cleaning trials began after eight
preliminary cleaning trails that followed this mixing procedure. It is likely that by this time, the majority of the previously separated grain and debris have undergone any changes due to conditioning of the particles. For the remainder of data acquisition cleaning trials, the amount of change in material properties of the grain/debris mixture should have reached a steady state.

Comparison of cleaning performance between various operational parameter configurations was more reliable by using data from physical measurements rather than calculated values of debris content. Total debris content of as-harvested material fluctuated across several cleaning trials. One reason this occurred may be behavior of the feed hopper. Grain and debris will naturally fall towards the exit chute at different rates due to slight differences in the previously mentioned angle of repose. This could have led to slight accumulation of debris in certain cleaning trials that was not observed in other cleaning trials. This inconsistency resulted in variations in the calculated debris loss values and separated seed values (composition of the lower container). Cleaning performance was then rated based on measured seed loss and measured separated debris.

Occasionally, the lower container was subject to further analysis (to measure debris loss and separated grain) but was not part of regular prescribed data collection. Upon inspections, lowest recorded debris loss for a single trial measured 0.02 pounds and highest recorded debris loss measured 0.11 pounds. Debris loss values and separated debris values were used to determine total debris content and to calculate extreme high and low boundaries of separation efficiency, shown in Table 7.
Table 7

*Conveyor Cleaner Separation Efficiency Range.*

<table>
<thead>
<tr>
<th>Operational Parameters</th>
<th>Debris Loss Minimum 0.02 lb.</th>
<th>Debris Loss Maximum 0.11 lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting HHH</td>
<td>95.1</td>
<td>78</td>
</tr>
<tr>
<td>Setting LHH</td>
<td>95.6</td>
<td>79.7</td>
</tr>
<tr>
<td>Setting HHL</td>
<td>93.7</td>
<td>78.9</td>
</tr>
<tr>
<td>Setting LHL</td>
<td>95.7</td>
<td>80.2</td>
</tr>
<tr>
<td>Setting HLH</td>
<td>95</td>
<td>77.5</td>
</tr>
<tr>
<td>Setting LLH</td>
<td>96.6</td>
<td>83.6</td>
</tr>
<tr>
<td>Setting HLL</td>
<td>95.4</td>
<td>79</td>
</tr>
<tr>
<td>Setting LLL</td>
<td>95.7</td>
<td>80.1</td>
</tr>
</tbody>
</table>

The scale that was used for weight measurements was subjected to a repeatability test. The test was done using two different weights. Table 8, below used a weight that was representative of the nominal seed loss measurements. Table 9 below used a weight that was representative of nominal separated debris measurements.
Table 8

*Scale Repeatability Test – Seed Loss*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Recorded Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.04</td>
</tr>
<tr>
<td>2</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>0.04</td>
</tr>
<tr>
<td>4</td>
<td>0.03</td>
</tr>
<tr>
<td>5</td>
<td>0.04</td>
</tr>
<tr>
<td>6</td>
<td>0.04</td>
</tr>
<tr>
<td>7</td>
<td>0.04</td>
</tr>
<tr>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>9</td>
<td>0.04</td>
</tr>
<tr>
<td>10</td>
<td>0.04</td>
</tr>
<tr>
<td>11</td>
<td>0.04</td>
</tr>
<tr>
<td>12</td>
<td>0.03</td>
</tr>
<tr>
<td>13</td>
<td>0.04</td>
</tr>
<tr>
<td>14</td>
<td>0.04</td>
</tr>
<tr>
<td>15</td>
<td>0.03</td>
</tr>
<tr>
<td>16</td>
<td>0.04</td>
</tr>
<tr>
<td>17</td>
<td>0.04</td>
</tr>
<tr>
<td>18</td>
<td>0.04</td>
</tr>
<tr>
<td>19</td>
<td>0.04</td>
</tr>
<tr>
<td>20</td>
<td>0.04</td>
</tr>
</tbody>
</table>

The scale repeatability test using a weight representative of the nominal seed loss measurements produced a standard deviation, $\sigma = 0.0036$ across the twenty trials. Additionally, with the scale resolution of 0.01 pounds, the scale has a precision uncertainty of one half of the resolution or 0.005 pounds.
Table 9

*Scale Repeatability Test – Separated Debris*

<table>
<thead>
<tr>
<th>Trial</th>
<th>Recorded Weight (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>0.43</td>
</tr>
<tr>
<td>3</td>
<td>0.43</td>
</tr>
<tr>
<td>4</td>
<td>0.42</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
</tr>
<tr>
<td>6</td>
<td>0.42</td>
</tr>
<tr>
<td>7</td>
<td>0.43</td>
</tr>
<tr>
<td>8</td>
<td>0.43</td>
</tr>
<tr>
<td>9</td>
<td>0.43</td>
</tr>
<tr>
<td>10</td>
<td>0.43</td>
</tr>
<tr>
<td>11</td>
<td>0.43</td>
</tr>
<tr>
<td>12</td>
<td>0.43</td>
</tr>
<tr>
<td>13</td>
<td>0.43</td>
</tr>
<tr>
<td>14</td>
<td>0.43</td>
</tr>
<tr>
<td>15</td>
<td>0.43</td>
</tr>
<tr>
<td>16</td>
<td>0.43</td>
</tr>
<tr>
<td>17</td>
<td>0.43</td>
</tr>
<tr>
<td>18</td>
<td>0.43</td>
</tr>
<tr>
<td>19</td>
<td>0.43</td>
</tr>
<tr>
<td>20</td>
<td>0.43</td>
</tr>
</tbody>
</table>

The scale repeatability test using a weight representative of the nominal separated debris measurements produced a standard deviation, $\sigma = 0.003$ across the twenty trials.

**Conveyor Cleaner Performance Analysis**

Using quantitative results from measured cleaning trials and qualitative results from experimental observations, several key points can be made on the cleaning performance of the friction based conveyor cleaner. Discussion points will be organized
by summarizing the observed effects of each operational parameter setting and explaining the associated impacts on cleaning performance.

For both seed loss data and separated debris data, the standard deviation from the mean, $\sigma_m$ was of interest as it represented the true value of the mean as several sets of data were taken. Standard deviation of the mean was calculated as expressed in Equation (1).

$$\sigma_m = \frac{\sigma}{\sqrt{n}} \tag{1}$$

In Equation (1), $\sigma$ = standard deviation and $n$ = number of trials. For all trials, $n = 5$, except setting LLH trials where $n = 4$ due to the elimination of data using Chauvenet’s criterion. Table 8 shows the calculations of $\sigma$, $\sigma_m$ and the associated confidence intervals using a $t = 1.638$ and $t = 1.533$ for settings LLH and all other settings, respectively. [17] The $t * \sigma_m$ represent a 90% confidence interval and were used for all error bars included in any graphs displayed in this chapter. Table 10 shows standard deviation and confidence internal calculations.
Table 10

*Mean Seed Loss, Separated Debris, Standard Deviations, and 90% Confidence Interval Values*

<table>
<thead>
<tr>
<th>Setting</th>
<th>Mean Seed Loss</th>
<th>Seed Loss, $\sigma$</th>
<th>Seed Loss, $\sigma_m$</th>
<th>$t*\sigma_m$</th>
<th>Mean Separated Debris</th>
<th>Separated Debris, $\sigma$</th>
<th>Separated Debris, $\sigma_m$</th>
<th>$t*\sigma_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHH</td>
<td>0.02</td>
<td>0.01</td>
<td>0.006</td>
<td>0.010</td>
<td>0.39</td>
<td>0.13</td>
<td>0.058</td>
<td>0.089</td>
</tr>
<tr>
<td>LHH</td>
<td>0.06</td>
<td>0.02</td>
<td>0.007</td>
<td>0.011</td>
<td>0.43</td>
<td>0.1</td>
<td>0.045</td>
<td>0.069</td>
</tr>
<tr>
<td>HHL</td>
<td>0.01</td>
<td>0.01</td>
<td>0.003</td>
<td>0.005</td>
<td>0.41</td>
<td>0.11</td>
<td>0.049</td>
<td>0.075</td>
</tr>
<tr>
<td>LHL</td>
<td>0.05</td>
<td>0.01</td>
<td>0.006</td>
<td>0.009</td>
<td>0.45</td>
<td>0.1</td>
<td>0.045</td>
<td>0.069</td>
</tr>
<tr>
<td>HLH</td>
<td>0.04</td>
<td>0.02</td>
<td>0.008</td>
<td>0.012</td>
<td>0.38</td>
<td>0.13</td>
<td>0.058</td>
<td>0.089</td>
</tr>
<tr>
<td>LLH</td>
<td>0.15</td>
<td>0.05</td>
<td>0.024</td>
<td>0.039</td>
<td>0.56</td>
<td>0.14</td>
<td>0.070</td>
<td>0.115</td>
</tr>
<tr>
<td>HLL</td>
<td>0.03</td>
<td>0.01</td>
<td>0.004</td>
<td>0.007</td>
<td>0.41</td>
<td>0.14</td>
<td>0.063</td>
<td>0.096</td>
</tr>
<tr>
<td>LLL</td>
<td>0.05</td>
<td>0.01</td>
<td>0.006</td>
<td>0.009</td>
<td>0.44</td>
<td>0.13</td>
<td>0.058</td>
<td>0.089</td>
</tr>
</tbody>
</table>

Deck Angle Influence on Cleaning Performance

Adjustments of the deck angle setting had the most significant impact on cleaning performance. This was especially visible in seed loss measurements. All four operational parameter configurations which contained a low deck angle setting (settings LHH, LHL, LLH, and LLL) exhibited the highest values of seed loss. Likewise the four remaining operational parameter configurations with a high deck angle (settings HHH, HHL, HLH, and HLL) exhibited the lowest values of seed loss.

Figures 27 and 28 graph cleaning performance data of setting HLL and setting LLL. These two operational parameter configurations share a low conveyor speed setting.
and a low feed rate setting. Figure 27 graphs seed loss values and Figure 28 graphs separated debris values. The difference in seed loss and separated debris was a direct comparison of the effect of deck angle setting.

**Figure 27.** Deck angle influence on seed loss (with common low conveyor speed and feed rate settings).
Figure 28. Deck angle influence on separated debris (with common low conveyor speed and feed rate settings).

Figures 29 and 30 graph cleaning performance data of setting HHH and setting LHH cleaning trials. Setting HHH and setting LHH shared high conveyor speed settings and high feed rate settings. These figures isolate deck angle effects on both seed loss and separated debris values. The high impact of deck angle settings are seen again in large differences in cleaning performance data when deck angle settings are isolated even under different conveyor speeds and feed rates as seen in figures above.
Figure 29. Deck angle influence on seed loss (with common high conveyor speed and feed rate settings).
Figure 30. Deck angle influence on separated debris (with common high conveyor speed and feed rate settings).

These results lead to the notion that the effects of deck angle settings were more independent than the other operational parameter settings. Recall that low deck angle settings will allow all material, seed and debris alike, to be more easily carried upwards by the conveyor and into the debris container. Because of this, both separated debris values and seed loss values increased under low deck angle settings. At high deck angle settings, seed loss values and separated debris values both decreased.

One reoccurring observation of high deck angle settings was the increased speed at which grain and debris would fall downwards on the conveyor surface. Many of the cleaning trails containing a high deck angle resulted in more turbulent behavior of falling
grain and debris. When grain or debris would collide with other particles, it would sometimes bounce and continued to travel downwards, mid-air. This phenomenon would increase the momentum of these grain and debris particles. The momentum of these particles can be problematic. The grain which is falling very fast may now collide with debris particles that are being carried upwards by the velvet fabric and force these debris particles back, downward. This process can lead to significant debris loss.

**Conveyor Speed Influence on Cleaning Performance**

Adjustments in conveyor speed settings had little effect on cleaning performance. Figures 31 and 32 compare cleaning performance data between settings LLL and setting LHL. Both operational parameter configurations share a low deck angle setting and low feed rate setting. Figures 31 and 32 effectively show cleaning performance differences based on conveyor speed settings. Changes in conveyor speed resulted in little change in both seed loss measurements and separated debris measurements.
Common Settings: Low Deck Angle, Low Feed Rate. A Comparison of Seed Loss Values as a Result of Conveyor Speed Settings. Seed Loss Values Represent Average Values of the Five Replicate Trials at Each Setting. Error Bars Show 90% Confidence Intervals.

Figure 31. Conveyor speed influence on seed loss (with common low deck angle and feed rate settings).
Figure 32. Conveyor speed influence on separated debris (with common low deck angle and feed rate settings).

Figures 33 and 34 compare cleaning performance data between settings HHH and setting HLH. Both operational parameter configurations share a high deck angle setting and high feed rate setting. Figures 33 and 34 effectively show cleaning performance differences based on conveyor speed settings. Both seed loss values and separated debris values decreased in comparison to setting LLL and setting LHL, shown above. Most notable is the small change in seed loss and separated debris values when conveyor speed is adjusted.
Figure 33. Conveyor speed influence on seed loss (with common high deck angle and feed rate settings).
Figure 34. Conveyor speed influence on separated debris (with common high deck angle and feed rate settings).

Much of the additional seed loss observed in settings LLL and setting LHL was likely associated with the low deck angle. However, high conveyor speeds and low conveyor speeds create unique grain and debris interactions. These differences are similar to the way that high deck angle settings create more turbulent behavior of falling grain and debris. Cleaning trails that contain high conveyor speeds appeared more violent and agitated than cleaning trials with low conveyor speeds.

This characteristic of cleaning dynamics altered how seed loss and debris loss occurred. Similar to effects of high deck angle, the more agitated behavior of grain and debris may have a tendency to bounce amaranth and debris particles off of the conveyor.
deck, resulting in increased downward momentum (which is desired for good seed, but undesired for debris particles). The more agitated behavior was beneficial in instances when large woody debris particles were fed onto the conveyor deck. There large woody pieces could act like a paddle, carrying seed and debris upwards into the debris container with it. This would occur more often at low conveyor speeds. At high conveyor speeds, however, material on the conveyor deck was more agitated and the large woody pieces would bounce more and not create the platform to carry additional material. Similarly, if a large piece of debris were to begin to carry material into the debris container, the grain would not remain stationary enough to continue to be carried upwards.

Conveyor speed settings had one other significant impact on machine operation - belt cleanliness. High conveyor speeds resulted in a cleaner belt during cleaning trials. At low conveyor speeds, some debris particles became stuck to the velvet fabric and travelled around the belt several rotations before being released. At high conveyor speeds, release of debris was greatly improved.

In a small scale food processing operation, machine characteristics such as machine sound and machine operator safety may be important factors. A high conveyor speed setting produced significantly greater sound while in operation. The high conveyor speed may also increase the risk of the machine operator in the event of required hands on interaction with the machine while cleaning is underway. The low conveyor speed setting was slow enough that the risk of catching a limb or clothing in the machine was very little.
Feed Rate Influence on Cleaning Performance

Variations in feed rate settings showed a moderate effect on cleaning performance. Figures 35 and 36 graph cleaning performance data of setting LLH and setting LLL. Both of these operational parameter configurations share a low deck angle setting and low conveyor speed setting thus isolating the effect of feed rate on cleaning performance. Figure 35 compares seed loss values and Figure 36 compares separated debris values.

![Figure 35. Feed rate influence on seed loss (with common low deck angle and conveyor speed settings).](image)

**Common Settings: Low Deck Angle, Low Conveyor Speed. A Comparison of Seed Loss Values as a Result of Feed Rate Settings. Seed Loss Values Represent Average Values of the Five Replicate Trials at Each Setting. Error Bars Show 90% Confidence Intervals.**
Figure 36. Feed rate influence on separated debris (with common low deck angle and conveyor speed settings).

Setting LLL seed loss value was the highest recorded value of all the operational configurations. The low deck angle and low conveyor speed were surely contributors to these results. Setting LLL was also an example of how operational parameters can be interdependent. The high feed rate setting produced a scenario where the conveyor deck surface was very full of material. In such cases, where the other two operational parameter settings favor upward movement (as opposed to high deck angle and high conveyor speed which produce more high speed material movement and agitated particle behavior), material had time to collect into piles and exacerbate seed loss. This buildup of
material on the conveyor deck also appeared to increase the amount of debris that would cling to the velvet fabric and travel around the conveyor. This was especially observed at low conveyor speeds where debris release from the fabric was already difficult.

Figures 37 and 38 graph cleaning performance data of setting HHH and setting HHL. Both of these operational parameter configurations share a high deck angle setting and high conveyor speed setting thus isolating the effect of feed rate on cleaning performance. Figure 37 compares seed loss values and Figure 38 compares separated debris values.
Interactions between Operational Parameters

Figures 27 through 38 show the effect of single operational parameter adjustments on cleaning performance. In several instances the effect of one parameter was easily represented. However these comparisons did not give any information on interactions between operational parameter. With three factors (deck angle, conveyor speed, and feed rate) and two levels (high and low settings of each factor), the data was applicable to a classical $2^3$ factorial ANOVA to show any interaction effects between operational parameters. Table 11 and Table 12 show the summary of the ANOVA.
Table 11

ANOVA Summary – Separated Debris

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect Estimate</th>
<th>F-value</th>
<th>% Contribution</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck</td>
<td>0.058</td>
<td>3.07</td>
<td>45</td>
<td>0.090</td>
</tr>
<tr>
<td>Conveyor</td>
<td>0.01</td>
<td>0.52</td>
<td>8</td>
<td>0.476</td>
</tr>
<tr>
<td>Feed</td>
<td>0.003</td>
<td>0.14</td>
<td>2</td>
<td>0.708</td>
</tr>
</tbody>
</table>

Interaction Effects

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect Estimate</th>
<th>F-value</th>
<th>% Contribution</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck-Conveyor</td>
<td>0.013</td>
<td>0.7</td>
<td>10</td>
<td>0.410</td>
</tr>
<tr>
<td>Deck-Feed</td>
<td>0.019</td>
<td>0.99</td>
<td>15</td>
<td>0.327</td>
</tr>
<tr>
<td>Conveyor-Feed</td>
<td>0.011</td>
<td>0.55</td>
<td>8</td>
<td>0.462</td>
</tr>
<tr>
<td>Deck-Conveyor-Feed</td>
<td>0.016</td>
<td>0.82</td>
<td>12</td>
<td>0.373</td>
</tr>
</tbody>
</table>

Table 12

ANOVA Summary – Seed Loss

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect Estimate</th>
<th>F-value</th>
<th>% Contribution</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck</td>
<td>0.026</td>
<td>42.04</td>
<td>51</td>
<td>0.000</td>
</tr>
<tr>
<td>Conveyor</td>
<td>0.006</td>
<td>10.10</td>
<td>12</td>
<td>0.003</td>
</tr>
<tr>
<td>Feed</td>
<td>0.008</td>
<td>12.67</td>
<td>16</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Interaction Effects

<table>
<thead>
<tr>
<th>Factor</th>
<th>Effect Estimate</th>
<th>F-value</th>
<th>% Contribution</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck-Conveyor</td>
<td>0.001</td>
<td>1.96</td>
<td>2</td>
<td>0.172</td>
</tr>
<tr>
<td>Deck-Feed</td>
<td>0.003</td>
<td>5.24</td>
<td>6</td>
<td>0.029</td>
</tr>
<tr>
<td>Conveyor-Feed</td>
<td>0.003</td>
<td>5.25</td>
<td>6</td>
<td>0.029</td>
</tr>
<tr>
<td>Deck-Conveyor-Feed</td>
<td>0.004</td>
<td>6.46</td>
<td>7</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The ANOVA verified earlier results showing deck angle settings provided a high impact on cleaning performance. The main effects dominate this process by contributing 79% of the seed loss results and 53% of the separated debris results.
CHAPTER VI: CONCLUSIONS

Success of the research project was gauged by adherence to project objectives. Any failures to meet project objectives were reviewed. Project objectives were as follows:

1. Develop a friction based amaranth grain cleaning method using upholstery velvet as the friction material. Prototype cleaning methods must be applicable to a working model that conforms to specifications as per Table 1, the Design Specifications table.

2. Conduct testing of the prototype amaranth seed cleaner to demonstrate seed cleaning performance both qualitatively and quantitatively as described in Methods section.

3. Compare experimental cleaning performance with product requirements based on cleaning performance found in literature.

The design specifications for the physical machine were closely met. Shortcomings in adherence to machine parameters were observed in feed rate capacity of the conveyor cleaner. Marginal desired feed rate was 50 lb/hr. The conveyor cleaner operated at feed rates of 4.5 lb/hr and 9.9 lb/hr in the low feed rate setting and high feed rate setting, respectively. For proof of concept testing of the friction based cleaning technology, the observed feed rate settings were acceptable. For future work and potential production of a similar conveyor cleaner, feed rate values were determined to be an area of improvement.
Testing procedures were carried out according to described methods. Alterations in methodology occurred in the presentation of data. Cleaning performance was rated based off of measured seed loss values and measured separated debris values. This method showed improved reliability over calculating cleaning performance based off of a calculated debris content value.

In comparison to findings during the literature review, the design specifications table can be used again for separation efficiency analysis. Marginal and ideal separation efficiency values were determined to be 98.5% and 95% clean. Table 7 showed separation efficiency results in best and worst case scenarios of debris loss. In best case scenarios with 0.02 lb. of measured debris loss, settings HHH, LHH, LHL, HLH, LLH, HLL, and LLL all met the marginal separation efficiency specification. Settings HHH, LHH, LHL, HLH, LLH, HLL, and LLL separated at 95.1, 95.6, 95.7, 95, 96.6, 95.4, and 95.7 percent efficient, respectively. In worst case scenarios with 0.11 pounds of debris loss, none of the operational parameter configurations met the marginal separation efficiency of 95%. Separation efficiency for settings HHH, LHH, HHL, LHL, HLH, LLH, HLL, and LLL were 78, 79.7, 78.9, 80.2, 77.5, 83.6, 79, 80.1 percent.

These results reinforced the potential of the friction based cleaning technology. The use of velvet as the friction material was originally thought of as a final cleaning process. Results from cleaning trials using as-harvested grain show good performance at ability to separate not only particles that were missed with an air screen separator but a wide range of debris particles. Further development of the friction based cleaner was
recommended based off of observed cleaning performance. Direction of future work is addressed in later sections.

**Recommended Operating Parameters**

Data collected from cleaning trials and experimental observations were both used to select machine operating parameter settings for best cleaning performance.

Deck angle settings consistently were the controlling operational parameter of seed loss values and separated debris values. High deck angle settings resulted in reduced seed loss and reduced debris separation. Low deck angles resulted in greater seed loss and greater debris separation. Based off of separation efficiency calculations, a low deck angle setting was recommended for future cleaning trials. The conveyor cleaner exhibited very small seed loss over the course of all cleaning trials. The increased separation efficiency gained at low deck angles was seen to be worth the expense of increased seed loss.

Conveyor speed settings had little effect of cleaning performance regardless of other operational parameter settings. Because the conveyor speed setting does not affect cleaning performance, the conveyor speed setting can be selected to achieve other desirable functions. Two considerations were machine operation characteristics and velvet condition. First, higher conveyor speeds may increase machine noise, increase machine power requirements, and possibly increase risk of injury to the machine operator. Finally, increased conveyor speeds improved conveyor belt cleanliness. High conveyor speeds are recommended over low conveyor speed settings.
Effects of feed rate settings on cleaning performance were difficult to conclude. A low feed rate setting is recommended for future cleaning trials. Seed loss values for cleaning trials containing a low feed rate setting were slightly lower than the average of all cleaning trials. Separated debris values for cleaning trials containing a low feed rate were slightly higher than average of all cleaning trials. Furthermore, experimental observations can conclude that low feed rate settings improve conveyor belt cleanliness.

Additional considerations for recommended operating parameters include different operational parameter settings to achieve a multi-pass cleaning operation. The design of a multi-pass cleaning operation would target specific outcomes during one cleaning trial. For the conveyor cleaner a first pass cleaning operation would target minimizing seed loss. A second pass would target debris separation. Minimizing seed loss would best be achieved at a high deck angle and a low feed rate. Optimal debris separation would be achieved at a low deck angle and low feed rate. The multi-pass method should be done in the order described because cleaning trials that are targeted to minimize seed loss will still separate a large amount of debris. This will provide a cleaner product to be sent through the cleaner on the second pass, possibly allowing for even higher feed rate.

Future Research

The conveyor cleaner was successful at demonstrating cleaning performance of a friction based grain separation device. The conveyor cleaner was however a prototype machine and several design improvements were suggested for future work. Suggestions from amaranth researchers at the International Amaranth Institute Conference lead to a
focus on using velvet fabric as the friction material. The next step in research of the friction based cleaner would be to expanded tests on various friction materials. Additionally, long term testing of the velvet fabric would provide useful information regarding durability of the fabric.

If further cleaning trials were to be tested using the conveyor cleaner it was recommended that the weighing process be made more precise. If similar experimental design was chosen, a more precise scale was recommended. In cleaning trials where minimal seed loss was observed (seed loss<0.02 pounds), the uncertainty of the scale could make up anywhere from approximately 30% to 50% of the measured weight. This could also be combated by changing the experimental design so that enough material was being weighted to reduce the uncertainty to below 10% of the total weighted amount.

Using as-harvested amaranth grain similar in composition to the batch tested, that would require cleaning trials that feed approximately 12 pounds of material per run.

The scope of this research was limited to testing amaranth grain. Results from the conveyor cleaner suggest useful application in cleaning and separating processes of different grains, seeds, legumes, or other foods. This technology is not restricted to sorting food. The friction based cleaning theory can be applied to any particles or objects that can be sorted by taking advantage of particle surface texture properties. Additional research of the application of such sorting process could unfold a plethora of useful applications of the friction based cleaning method. This research could lead to variations of machine design and broaden the range of application of the friction based conveyor cleaner.
The scale of the prototype conveyor cleaner was effective at providing a realistic cleaning scenario for small scale food processing. The ability to size up or size down a friction based conveyor cleaner would further broaden the applicable range of this separation technology. Useful tests may include cleaning trials on the conveyor cleaner with a series of reduced velvet areas. Determination of how working deck area impacts available material throughput would better inform design decisions for a larger production model. On a device such as the conveyor cleaner, conveyor belt width would be the dimension that governs grain handling capacity. If conveyor width increases, feeding of grain must be setup to maintain even grain distribution about the width of the conveyor belt. Additional considerations of scaling up include added control of material during cleaning. Minor seed and debris losses on the experimental cleaner were negligible. If feed rates were to increase several magnitudes to the marginal or ideal value of 50 lb./hr and 100 lb./hr, minor seed and debris losses would impact cleaning performance results.
REFERENCES


