Bee Pollen Dehydrator

Final Report

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Submitted to: Professor Ruihong Zhang, EBS 170C

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Thank you to all those who lent us equipment, including Dr. Ruihong Zhang, Dr. Bryan Jenkins and the PG & E lending library.

Executive Summary

This senior design project had the goal of developing a bee pollen dryer that would meet the needs of beekeepers in the Cundiboyacanse high plateau region of Colombia. Beekeepers in Colombia collect 30-40 kg of high value bee pollen per week, but have no means of economically and effectively preserving it. The pollen moisture content ranges from 18-34% at the time of harvest, and is susceptible to microbial growth that causes spoilage in the pollen. The goal of our dryer was to dry pollen to a moisture content of 4-6% in order to prevent spoilage.

The overall objective in Winter Quarter was to create a small-scale prototype solar dryer that could effectively dry pollen. During winter quarter, we decided on the design of our dryer. After researching many dryers, we took the best components of a solar dryer developed by Appalachian State University and a desiccant integrated dryer developed by Anna University, combined them and made additional modifications. We used the frame of the Appalachian State University dryer but made the top and the lathe in the heating chamber removable. We used the desiccant mixture from the Anna University Dryer since it had already been proven effective in high humidity conditions. Additionally, we modified the dryer trays so air would be forced to move over the top and bottom of the pollen rather than through it. We began building our dryer prototype that had a 5 kg capacity. At the same time, we started testing small grains (quinoa and rice) that could be used as less expensive models of pollen.

In spring quarter 2015 we completed construction of our dryer and began testing. We tested the internal temperature of the dryer, internal air velocity, change in moisture content over time, and effect of desiccants on pollen moisture content. Our goal was for the temperature in the dryer to reach, or exceed, 50ºC. The peak dryer temperature was at least 50ºC every day data was collected, with an overall peak temperature of 60ºC. The velocity ranged between 0.1-0.3 m/s. After comparing the drying curve of rice and pollen in the dryer, we concluded that rice was a suitable model for pollen in the drying trials. We found the most significant drying occurred during the first day and that additional drying days were unnecessary. While the rice on the bottom shelf was able to reach the target moisture content of 4-6%, rice on higher shelves finished at moisture contents of 8-16%. Rice product was sealed with desiccants at night to determine their effect on drying duration, but little effect was observed. We recommend that future dryers be modified with weather stripping to seal the drying chamber. We also recommend the use and ratio of desiccants to pollen be researched further to determine its effect, if any, on the duration of drying.

Problem Statement and Background Material

Problem Statement

Bee farmers in Colombia collect 30-40 kg of high value bee pollen per week, but have no means of economically and effectively preserving it. The pollen moisture content ranges from 18-34% at the time of harvest, and is susceptible to microbial growth that causes spoilage in the pollen. The pollen must be dried to a moisture content of 4-6% to prevent spoilage. The moisture content of Colombian bee pollen farmers dry bee pollen varies widely, and the average moisture content of dried pollen only reaches 7.7%. There is also not a standardized storage method for bee pollen post drying in Colombia, which could result in the rehydration of the pollen if it is not stored in a cool, dry environment (Fuenmayor C. , et al., 2013). If a low cost bee pollen dryer that lowers the moisture content of pollen to 4-6% can be developed in conjunction with a storage method, Colombian bee pollen farmers will have a significant added source of income.

Prior Art

There are several existing products and processes for drying bee pollen, but no prior art completely addresses this project's problem statement.

The Fuijan University for Agriculture and Forestry developed a bee pollen dryer that was lightweight, aerated by an electric fan, and heated by an electric heater. The temperature of the chamber is read on a built in thermometer, and a knob on the front of the chamber door can adjust the temperature. The dryer, illustrated in figure 1, has a capacity of 3 kg of wet bee pollen and has a chamber with holes drilled into it that allow for airflow. The dryer is able to create 3 kg of dry bee pollen in 8 hours using 300 W of electricity, translating to 2.4 kWh of power usage per 3 kg of pollen dried (China Patent No. CN201897368 U, 2011). This drier may be effective for farmers with small amounts of bee pollen, but it is not feasible for the beekeepers, who produce 30-40 kg of bee pollen per harvest and would require 10-14 dryer batches per harvest. Additionally, this design is dependent on electricity, an amenity that is intermittently available to farmers in Bogota.

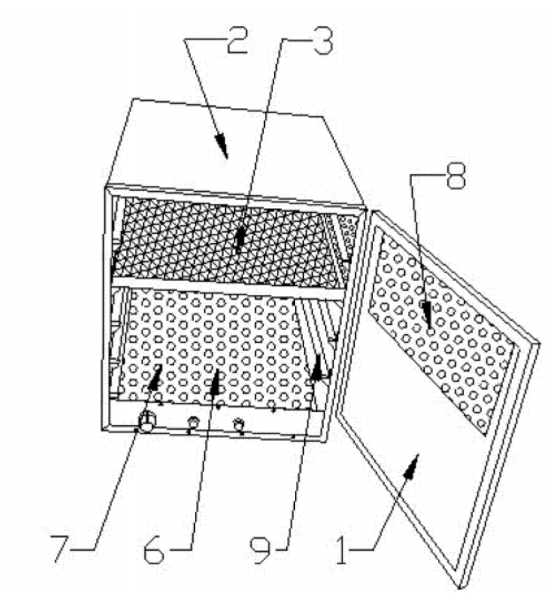

Figure 1: Bee pollen dryer developed and Fuijan University

Solar ovens and solar concentrators that are designed for drying fruit may be applicable in drying bee pollen. Solar ovens concentrate radiation from the sun in a closed container, heating the air in the enclosure and increasing its capacity to absorb moisture. Operating on the same principle as solar ovens, solar concentrators are parabolically shaped reflectors that are directed at an enclosure, but are not directly attached to the enclosure. For purposes of dehydration, the enclosure receiving the concentrated radiation should be well ventilated to increase air velocity and to keep temperatures low enough to prevent denaturing of proteins in the food. A solar concentrator system for tomato dehydration was developed in Dr. Ruihong Zhang's lab at the University of California, Davis. The solar concentrator decreased the time to dehydrate a tomato by 21% over a dryer without the concentrator, and did not significantly affect the tomato quality. However, solar driers are dependent on sunlight and low cloud cover, which can be a major limitation if the food product cannot be dried before microorganisms propagate in the food. (Ringeisen, 2011).

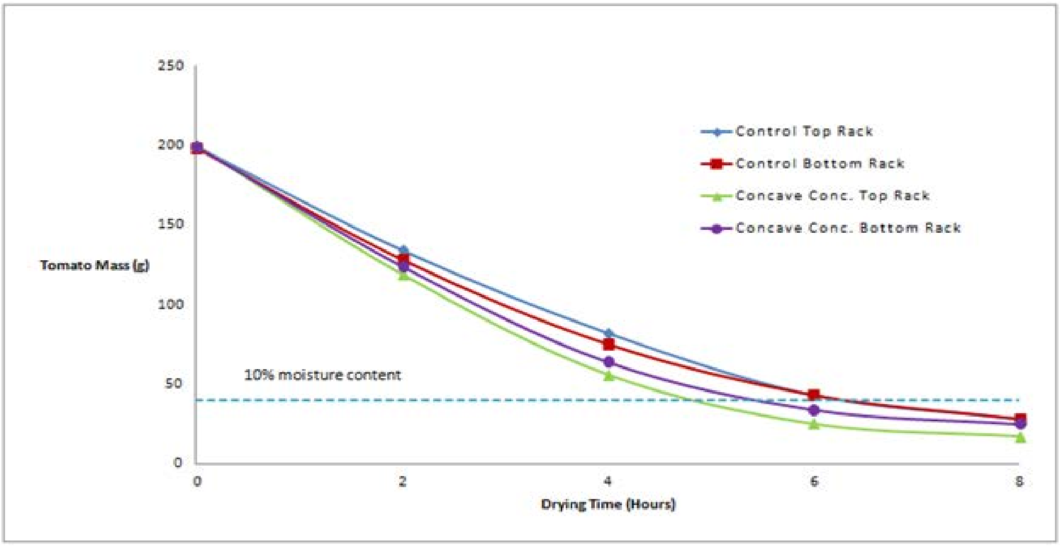

Figure 2: Graph showing the drying time difference between a control dryer and a dryer with a solar concentrator.

The most promising design found in prior art for bee pollen drying is the solar fruit dryer illustrated in figure 3.

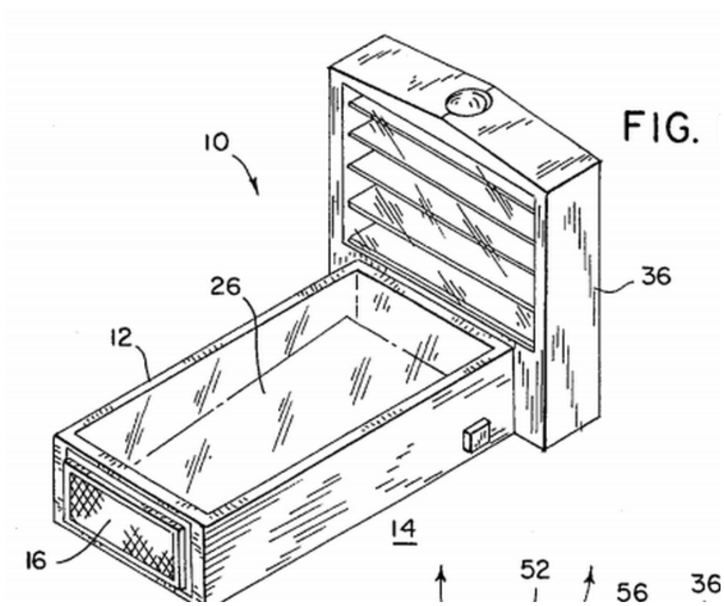

Figure 3: Solar fruit dryer with enclosed glass chamber and aerating fans.

The dryer is comprised of a solar concentrating compartment (26) that both directs solar energy at the fruit drying compartment (36) and heats air flowing into the fruit drying compartment (16).

The fruit is placed on racks that are inserted into the fruit drying compartment, which is covered on its face with plexiglass. Under full sunlight, the compartment reaches temperatures of 51-57 °C, and moisture filters are inserted on the sides of the drying compartment to ensure dry air is flowing over the fruit. Dual fans are mounted on each side of the inflow entrance, and an exhaust fan is mounted on the top of the drying rack. The drying compartment is 84 inches wide and 20 inches deep, with room for 5 trays to be inserted (United States Patent No. US5584127 A, 1996). Elements of this design may be useful when designing a solution specific to bee pollen drying in Cundiboyacanse high plateau, and further research into the bee pollen capacity of this dryer and the operating temperature in non-ideal conditions must be done to determine its efficacy for the problem statement established in this paper.

While we considered the designs above, our dryer design is principally based on a dryer developed by Appalachian State University. Researchers at Appalachian State University optimized this passive solar dryer design through 20 years of testing and evaluation. The dryer takes in air through its low set entrance, heats air as it flow diagonally up through a solar collector box, and dries biological material as it flows up through food trays and out of adjustable vents. The solar collector box comprises a metal lathe sheet that helps heat the flowing air and a fiberglass reinforced polyester covering that allows for maximum solar radiation penetration. The vents are adjustable to control temperature and airflow.

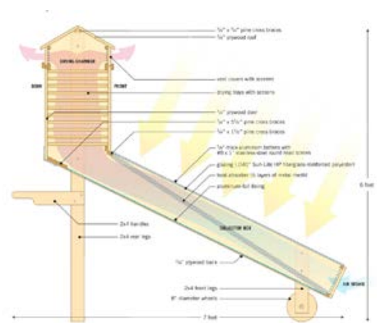

Figure 4: Appalachian State University Solar Dehydrator Design

Our design is also inspired by a desiccant integrated solar dryer developed at Anna University in India. This design uses a fan to force airflow through the dryer and a solar collector plate to heat the air. The air flows up through wet biological material and out vents at the top. There is additionally a separate chamber on the top of the dryer filled with a desiccant mixture and covered with a plastic that allows for direct dryer of the desiccants. At night, the top desiccant chamber is opened to the chamber containing biological material and the dryer entrance and exit are closed to allow drying to continue throughout the night. This dryer has a peak temperature of 80ºC.

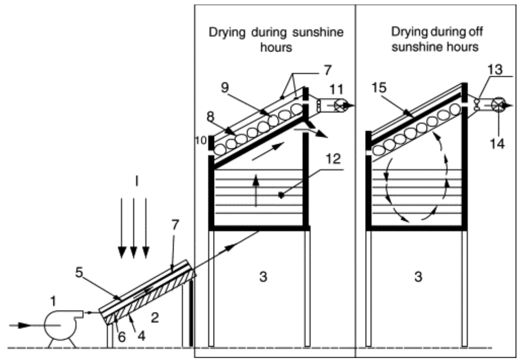

Figure 5: Anna University Desiccant Integrated Dryer

Ideas for Addressing the Problem

We combined the Applachian State Univeristy and the Anna University solar dryer designs above to address our problem. Our solution was to combine the passive solar dryer design mentioned above with the desiccant integrated dryer so achieve both airflow without electricity and to prevent moisture recharge in the pollen during the night, an important consideration Colombia's high humidity environment. We additionally modified the passive solar dryer design (Fig 4.) to induce airflow in a zig-zag pattern over the pollen. Since the pollen is too densely packed to allow airflow through its pores, we created a gap in each of the trays that covered about a quarter of the tray area. The gaps were placed on alternating sides of the dryer to allow air to flow over each layer, as is illustrated below in (Fig 6).

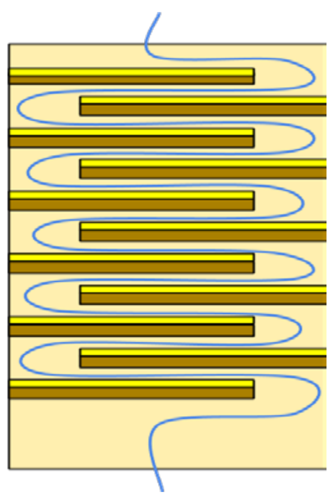

Figure 6: Cross section of modified Appalachian State University dryer

Goal and Objectives of Engineering Design

The long-term goal of this project is to develop and test a usable bee pollen dehydrator for small-scale beekeepers in Columbia. Specifically, the goals are to: 1) Design a dehydrator that can produce dried bee pollen with a consistent moisture content 2) Scale the dehydrator so it can dry the volume of bee pollen produced on a weekly basis at the bee farms and 3) operate reliably without electricity.

Specific Objectives:

1. Research pollen drying techniques that do not require electricity and preserve the nutritional characteristics of the pollen. Research specifically, the potential of combining desiccant materials and solar drying methods.

2. Design a value chain for bee pollen from hive to market in order to identify the areas where the pollen is susceptible to moisture contamination and develop a systematic method to prevent pollen quality degradation.

3. Build small-scale (approx. 4kg) bee pollen dehydrator prototypes that are solely dependent on solar power, desiccant drying, or both.

4. Evaluate the dried bee pollen produced by the prototypes for moisture content

Objective 1: Optimize prototype performance

Task 1a: Outline quantitative methods of measuring dryer performance (i.e. temperature and airflow with a given humidity and solar radiation)

Thermocouples and an anemometer (borrowed from Kameron Chun's lab) will be used to test temperature and airflow, respectively. Temperature will be measured in the main dryer chamber and airflow will be measured in the air tunnel in accordance with Jim Thompson's instructions. A pyranometer needs to be located to test solar radiation incident on the dryer, and compare it to solar radiation conditions in Colombia.

A replica prototype may have to be built in order to be able to more directly compare the variable conditions of the dryer (i.e. temperature and airflow values given certain physical modifications)

Task 1b: Test dryer performance in drying pollen and pollen model (most likely quinoa)

Pollen and quinoa will be loaded into trays and their moisture contents will be recorded on a regular interval by sampling the material being dried. Dryer performance will be evaluated based on how fast pollen dries. Dryer testing will take place at the UC Davis Western Agriculture Center.

Task 1c: Evaluate drying performance of pollen during nighttime hours

The dryer will be sealed and various ratios of desiccant: pollen will be tested to determine the effectiveness and worth of the desiccant as a drying material.

Task 1d: Resign dryer and repeat task 1a and 1b

The dryer will be physically modified to increase the airflow as much as possible while keeping the temperature close to 50 degrees Celsius as possible.

Objective #2: Build a full scale dryer prototype and test performance

Task 2a: Scale up design of optimized prototype to build our final dryer prototype

Proportionally scale up the design of optimized prototype to include a capacity of 40 kg and construct the design at the Western Agriculture Center.

Task 2b: Test performance of prototype and present results at senior design showcase

Do a final test run of the dryer (ideally using pollen as the drying material) to evaluate the performance of the dryer, which will be determined by water weight loss of pollen do to heated air drying and desiccant drying.

Objective #3: Design a pollen storage system

Task 3a: Design a storage system based on literature research

Research postharvest storage methods for pollen and other grains, keeping Colombian beekeepers current practices and goals for pollen storage in mind.

Task 3b: Test storage system with pollen dried by prototypes

Store pollen in the developed storage system and evaluate storage system performance based on visual presence of microbial growth.

Description and Specifications of Final Design Product

The goal of this design is to create a bee pollen dryer in which drying is driven by passively heated solar energy. The dryer is designed to induce maximum airflow with an internal temperature of 50 C.

Our dryer comprises two main compartments: a solar collector box and a drying chamber. The solar collector includes a polycarbonate plastic top, which allows for penetration of solar radiation, several layers of metal lathe sheets, which absorb incident solar radiation, and a reflective aluminum lining, which increases the amount of available solar radiation in the collector box. The drying chamber is filled with vertically stacked trays that hold the pollen product. Three quarters of each tray is covered with a nylon mesh that holds the pollen with the remaining quarter left empty to allow for airflow. Each of these 12 trays rest on a shelves inset to the side of the drying chamber. The top of the chamber includes adjustable vents that slide on guides to adjust the size of the dryer outlet. A door was installed in the back of the drying chamber that is held closed by two metal latches on either side of the exterior of the drying chamber. The dryer is held upright in the back by two planks of wood on either side of the drying chamber and in the front by two wheels on either side of the collector box that allow for dryer mobility. The dryer body is made entirely out of wood.

Air flows through an entrance at the bottom of the solar collector box, where it is heated by the sun and metal lathe sheets, and diagonally upward towards the drying chamber. The air then flows through the empty quarter of each tray, which are positioned in alternating order to force air over the pollen in each tray layer (figure 6), and out through the vents at the top of the drying chamber.

Materials

- One 4-by-8-foot sheet of 3/4-inch plywood, exterior grade
- One 4-by-8-foot sheet of 1/4-inch plywood, exterior grad
- Five 1-by-6s, 8 feet long, pressure-treated
- Two 2-by-4s, 8 feet long, pressure-treated
- 2 wheels, 8-inch-diameter
- 36-inch-long, 1/2-inch-diameter steel axle
- 2 heavy-duty hinges
- Six 27-by-96-inch sheets of metal lath
- 3 square feet nylon mesh
- One 2-by-6-foot sheet of FRP (fiber-reinforced plastic)
- 30 square feet food-grade screening
- Heavy-duty aluminum foil, 25-foot roll
- 3/4-by-1/8-inch aluminum battens, 16 feet total length
- 1 1/4-inch No.8 exterior-grade Phillips flat-head screws (100 or more)
- 1 5/8-inch No. 8 exterior-grade Phillips flat-head screws (about 30)
- 1-inch No. 8 round-head screws (about 20)
- Eight 3/8-by-3-inch bolts, nuts and washers
- Four 3/8-by-4-inch bolts, nuts and washers
- 4 hook-and-eye fasteners
- 1/4-inch staples
- Exterior-grade latex paint and primer, any light color
- High-temperature spray paint, black
- Waterproof glue
- Silicone caulk
- Weather stripping
- Roofing

Tools List

- Circular saw with rip guide
- Router with 3/4-inch straight bit and cutting guide
- Electric drill with No. 8 pilot-hole and countersinking bits
- 2 sawhorses
- Long straightedge
- Marking pencil

- Protractor
- Framing square
- Level
- Tape measure
- Staple gun
- Caulk gun
- Wrenches
- Clamps

Figure 7: Completed dryer flanked by two beautiful EBS students

Figure 8: Dryer side specifications

The dryer frame should be cut using a circular saw to the specified dimensions in figures 8 and 9 out of plywood sheets. Two dryer sides should be cut, four vent covers, one dryer door, one dryer bottom and one dryer front. Each of the cut plywood pieces should be primed and painted to form a protective coating that prevents warping. The dryer sides and bottom (not shown) should be attached and support struts should be installed as indicated in figure 11. The drying chamber should be constructed and installed on top of the solar collector box. The drying chamber door should be hinged on the bottom and held closed by simple latches on top. Weather stripping should be installed along the sides of the dryer flush with the dryer door to ensure an airtight chamber. Twelve ¾'' shelves should also be installed in the dryer with 1'' spacing between each shelf starting at the base of the drying chamber. The roof and weather stripping should be installed on the top of the drying chamber, and both legs and the pair of wheels should be bolted in the dryer sides as indicated in figure 10. The aluminum sliders, metal lathe, and plastic sheet can then be installed on the collector box to complete the dryer.

Trays can be constructed by connecting ¾’’ plywood and stapling on the nylon mesh, as shown in figure 12.

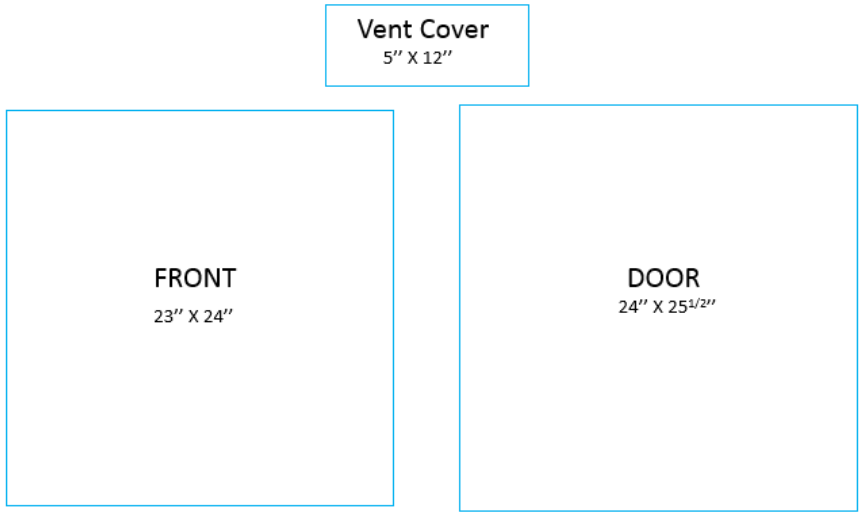

Figure 9: Drying chamber front, door, and vent cover specifications

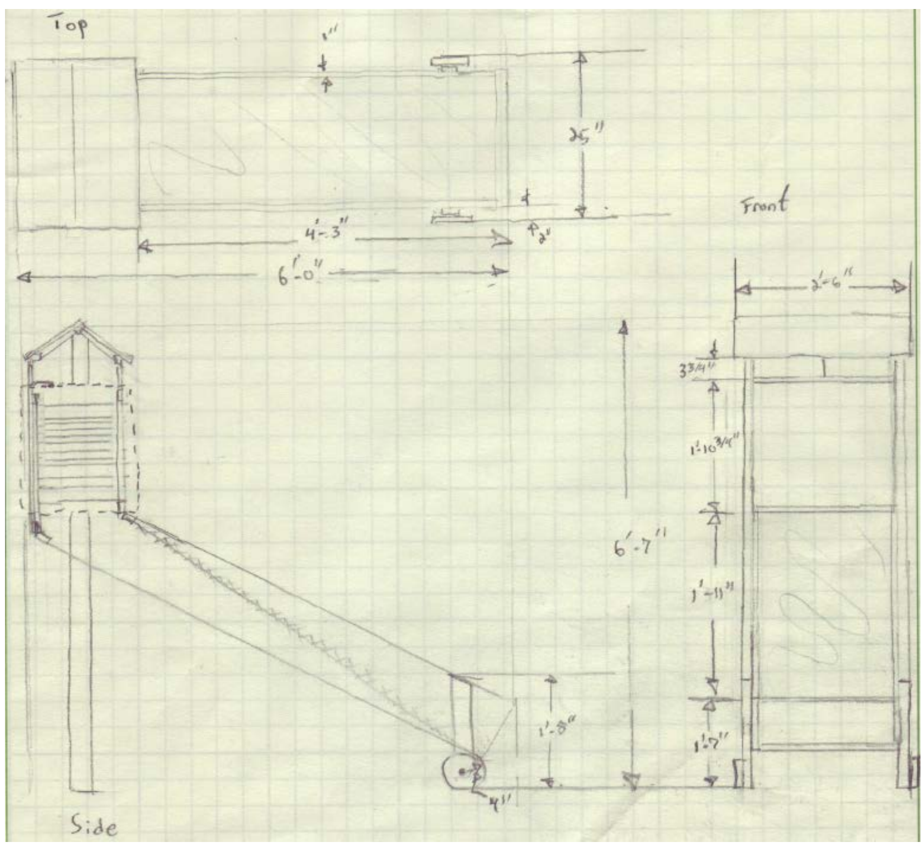

Figure 100: Engineering drawing and dimensions of dryer

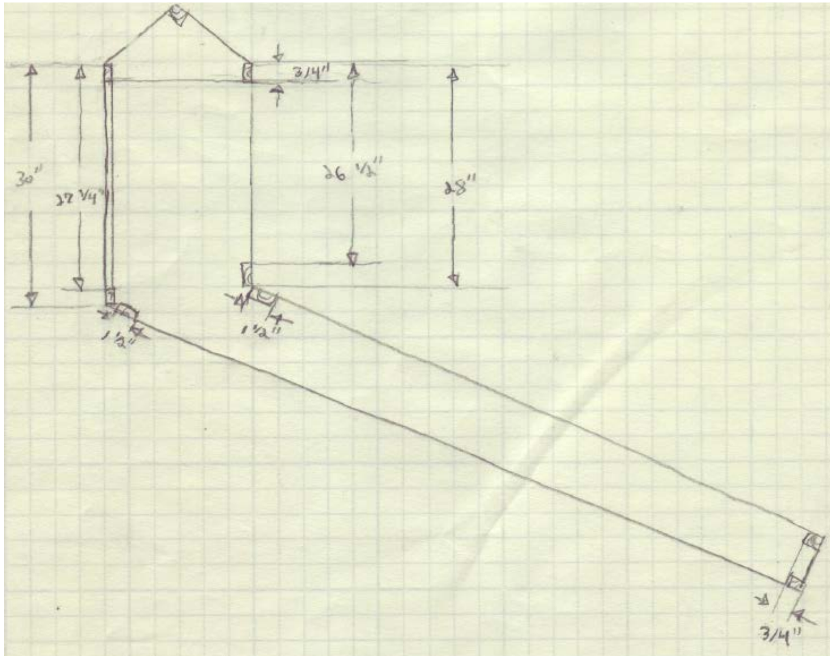

Figure 11 Dryer support struts

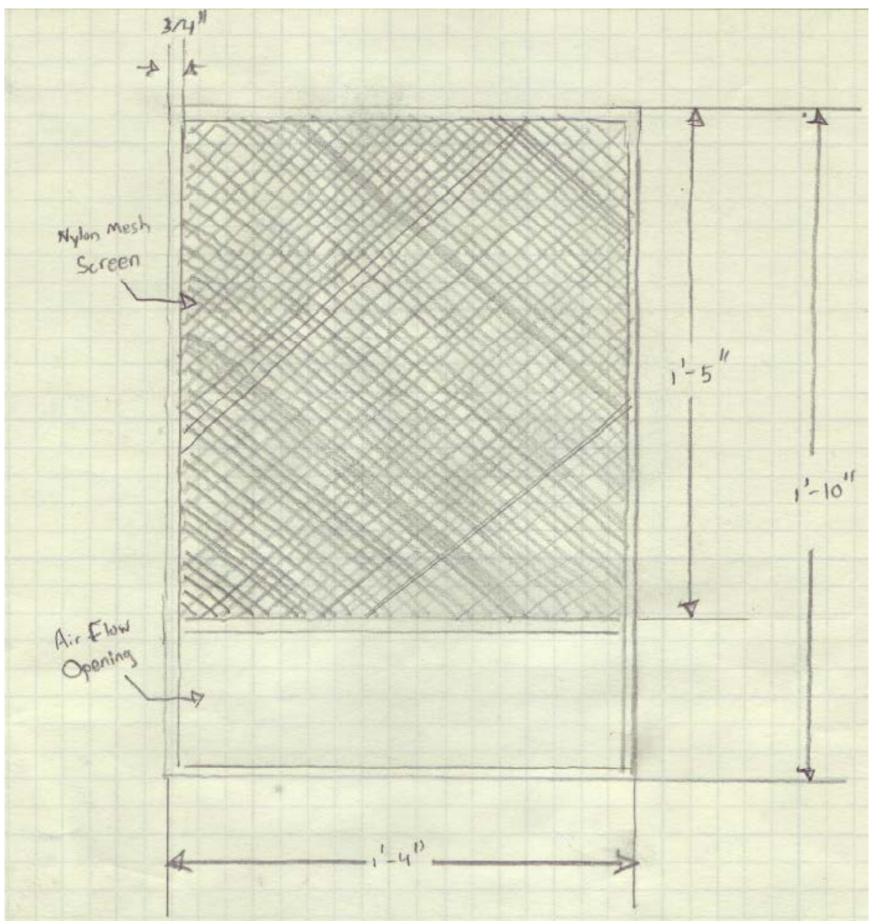

Figure 12 Dryer pollen tray

Figure 13: Pollen trays seen in back of pollen dryer

Figure 14: Solar collector box and metal lathe sheet with polycarbonate plastic removed.

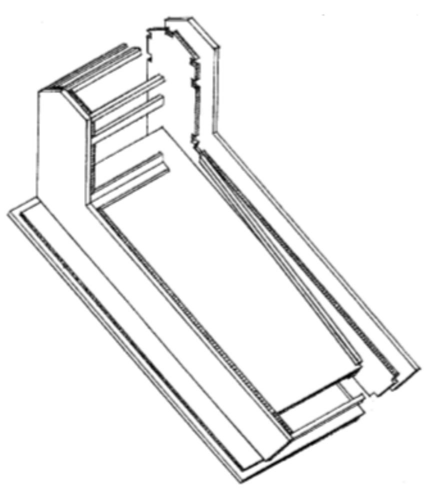

Figure 15: Expanded view of dryer body and support struts

Desiccants

The desiccant mixture can be prepared by mixing 10% calcium chloride, 20% vermiculite, 10% cement, and 60% sodium bentonite clay by weight. The desiccant should be placed on two drying trays in a centimeter thick layer. A piece of plywood the size of the drying trays sided with weather stripping should be used to seal the bottom shelf of the dryer during nighttime hours.

Performance Evaluation of Final Design Product

The main areas we focused on while testing the dryer were the relationship between the ambient and drying chamber temperature, the air velocity inside the dryer, and the drying medium's moisture content relative to time.

While there are multiple other factors that impact the overall performance of the design, like radiation and relative humidity, the limitations of our resources and time prevented us from investigating the impact of these other relevant variables.

Dryer Temperature

The internal drying chamber temperature relative to the ambient temperature was monitored continuously over 5 days. The temperature was recorded by placing thermocouples and data loggers on the top tray of the heating chamber, on the bottom tray of the heating chamber and then in the ambient air next to the dryer. The first drying trial took measurements from the afternoon of May 6th through the evening of May 8th (figure 16). The second trial was performed from the morning of May 29th through the evening of June 1st (figure 17)

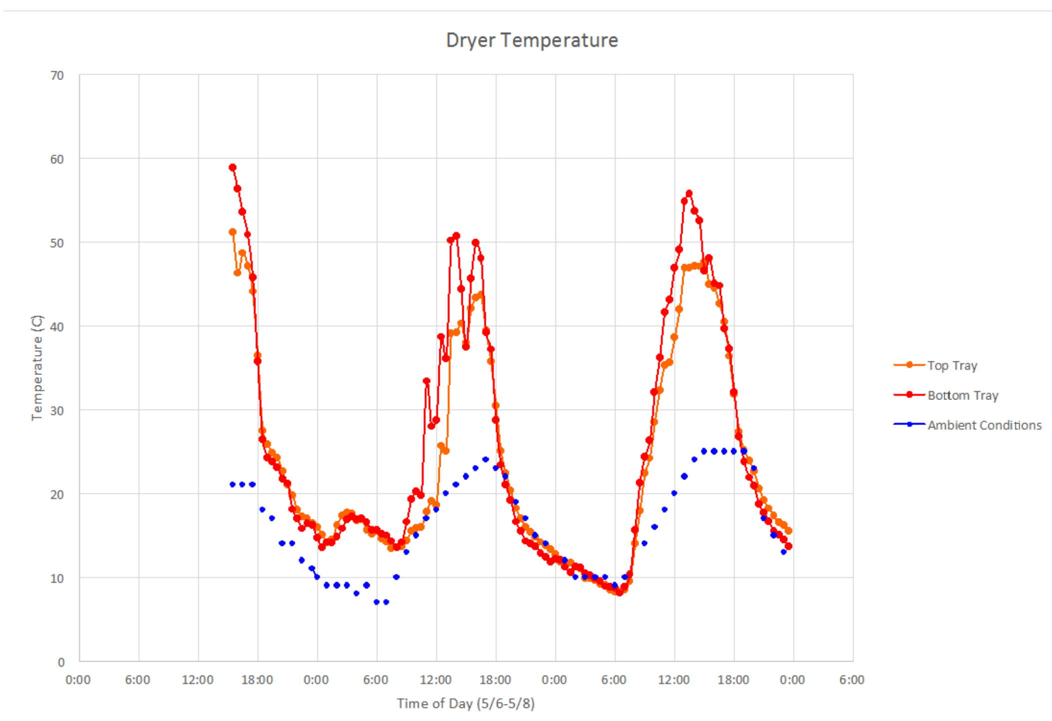

Figure 16: Temperature profile for the top tray, bottom tray and the ambient temperature. Recorded from May 6-May 8.

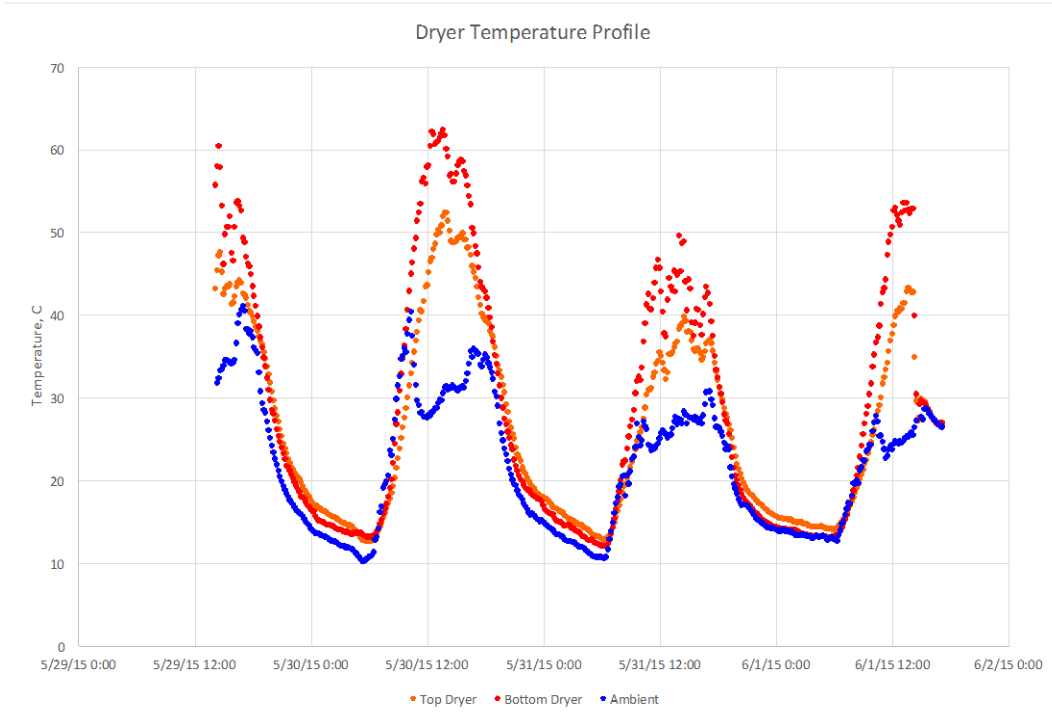

Figure 17: Temperature profile for the top tray, bottom tray and the ambient temperature. Recorded from May 29-June 1

Our plan with this dryer was to overshoot our goal temperature of 50ºC because it is easier to make modifications that lower the temperature of our dryer than modifications that increase the temperature. Another reason we wanted to do this is because the solar radiation in Colombia is lower than it is in Davis where the temperature tests were performed. The temperature in the dryer surpassed 60ºC on multiple days and always reached 50ºC for at least part of the day. During the hottest part of each day the temperature inside the dryer was consistently 25ºC hotter than the ambient temperature and frequently peaked at a difference of 30ºC.

Dryer Velocity

Lathe vs. No Lathe

The heating chamber contains a removable lathe. In order to understand the relationship between the lathe and the velocity and temperature within the drying chamber, the velocity was measured at 18 different points and temperature was measured at 9 different points when the lathe was in the dryer and again when the lathe was removed from the dryer. When these measurements were taken, the average temperature was 3.72ºC higher when the lathe was in the heating chamber and the velocity was 0.1m/s lower (table 1).

Table 1: Temperature and Velocity within dryer with and without the lathe present in the heating chamber.

	Temperature (ºC)	Velocity (m/s)
With Lathe in Dryer	33.42	0.25
Without Lathe in Dryer	29.70	0.35

The temperature was expected to be higher with the lathe in since the air is forced to move through the hot metal to reach the drying chamber. Additionally, the velocity was expected to be lower since moving through the openings in the lathe interrupt the natural air flow.

Velocity with Respect to Temperature

To determine the relationship between temperature and velocity, the velocity and temperature were measure above three trays. The velocity was measured at 6 evenly distributed points above each tray and the temperature was measured at 3 points above each tray. The average velocity and temperature was calculated for each reading. The readings were performed three times throughout the day for three days. The velocity was then plotted against temperature in figure 18. While no clear relationship was established between the two variables, the vast majority of velocity measurements fell between 0.1-0.3 m/s.

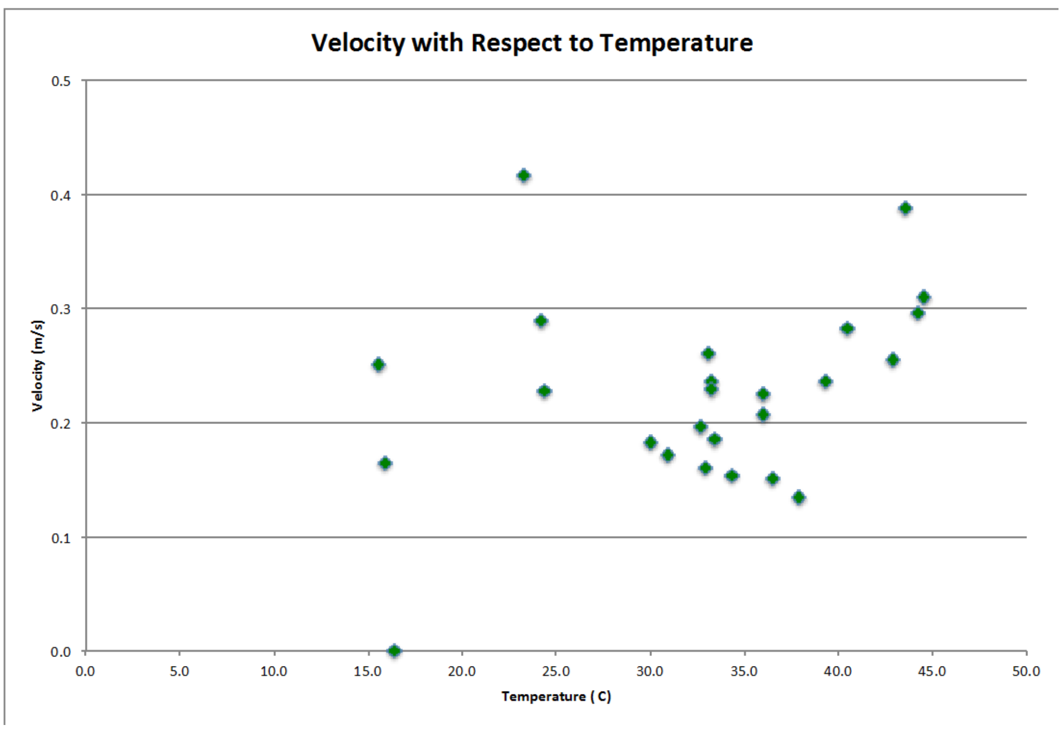

Figure 18: Velocity with respect to Temperature inside the dryer.

Pollen Model

Our goal was to create a bee pollen dehydrator that could lower the bee pollen moisture content down to 4-6% in 24 hours. Because bee pollen is so expensive, we looked into finding a suitable model for bee pollen. Bee pollen has moisture content of 34% on the high end; we found soaking rice in cold water for eight hours brings its moisture content up to 34%. We determined this by leaving rice in a bowl of cold water for eight hours, weighing a sample and then weighing it again after drying that sample in a 100ºC oven for 48 hours.

Equation 1: Moisture Content, Wet Weight Basis

$$MC(w.b.) = \frac{Wet\ Weight - Dry\ Weight}{Wet\ Weight}$$

After determining that the soaked rice and the pollen had similar starting moisture contents, we dried them at the same time in the dryer over four hours. To monitor drying activity, we took weight measurements of both, the rice and pollen every hour (figure 19).

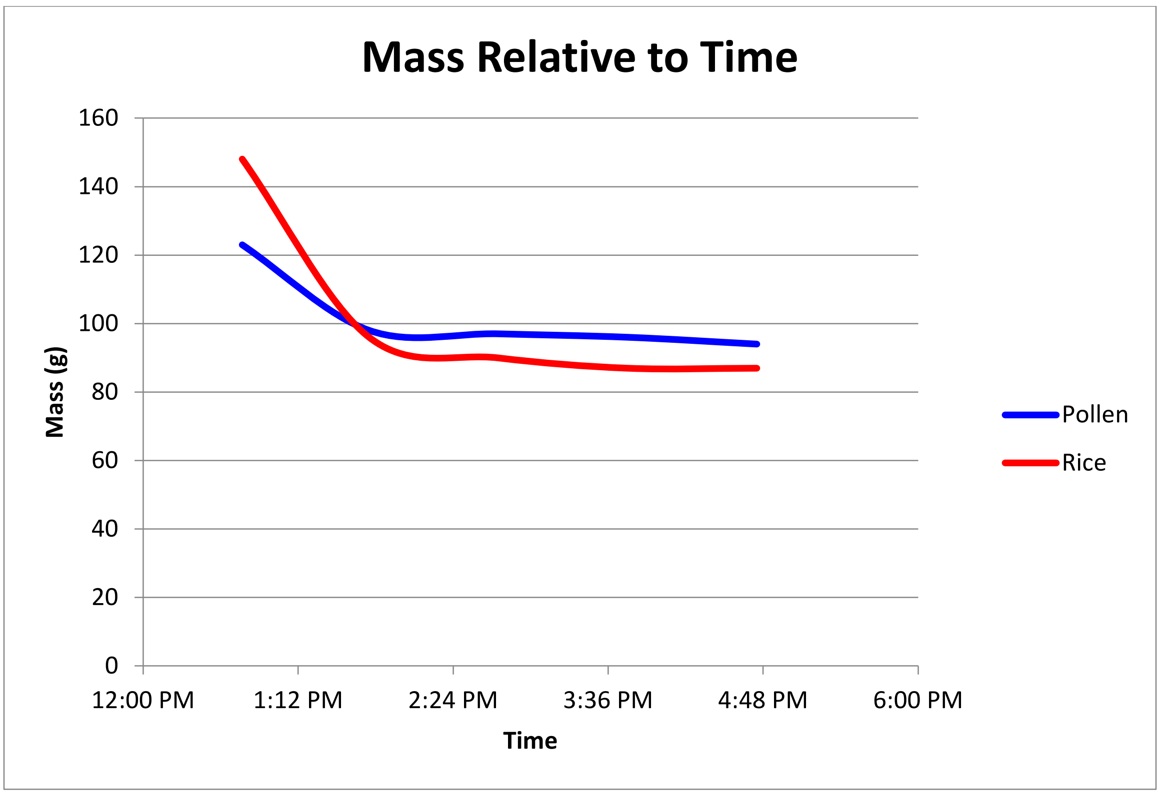

Figure 19: Pollen and Rice mass with respect to time

The rice and pollen both lost the majority of their moisture in the first hour and then continued to slowly loose water over the following three hours. From this trend, we concluded that the rice was a suitable substitute for pollen in the moisture content trials.

Moisture Content

Rice Dehydration Experiment Overview

Overview

This experiment did not include the use of desiccants. It was the method used for measuring the rice moisture content over a 48+ hour period.

Method

Rice was soaked in a bowl of cold water for eight hours. The rice is then removed from the water and placed on drying trays. The initial weight of each tray (without rice) was measured and recorded. The weight of the trays with rice were measured and recorded. A sample of this initial "wet rice" was taken and placed in a small plastic bag. All of the trays are placed in the dryer.

The sample of wet rice was then taken to the lab and placed in three pre-weighed drying tins. The drying tins were placed in 100^{o}C oven for 48 hours. After 48 hours elapsed these tins were weighed again. The initial moisture content of the rice placed in the dryer was determined from the samples by using equation 1. The average of the three moisture contents was then determined (MC,i).

The "dry weight" of the rice on each tray was then calculated by use of equation 2.

Equation 2: Complete Dry Weight

$$DW, final, x = weight, initial, x * (1 - MC, i)$$

Every evening around 5pm and every morning around 11 am, each tray in the dryer containing rice was weighed. The moisture content of the rice at that point was determined by equation 3.

Equation 3: Moisture Content While Drying

$$MC, current, x = (WW, current - DW, final, x)/WW, current, x$$

The information gathered was then plotted against time to see how the moisture content varied between trays and over time.

Dryer Experiment 1: Change in Rice Moisture Content over 50 hours, April 30-May 2, 2015

Overview

White Jasmine rice was soaked in a bowl of cold water overnight for eight hours. This rice was then placed on three trays, a top (B), middle (G), and bottom (L) tray. The rice was then weighed every morning and night, for 50 hours. It was weighed a total of five times.

Results

Table 2: Ambient Climate Conditions 4/30 - 5/2

Date	Mean Temp. (F)	Max Temp. (F)	Min Temp. (F)	Mean Humidity (%)	Max Humidity (%)	Min Humidity (%)	Wind Speed (mph)
4/30	73	87	59	29	77	12	8
5/1	72	91	53	35	67	12	4
5/2	68	86	51	54	88	25	7

Table 3: Weight of rice (g) at various times throughout the drying process

Date	**Thurs. 4/30**	**Thurs. 4/30**	**Fri. 5/1**	**Fri. 5/1**	**Sat. 5/2**
Time	**11:30 AM**	**5:30 PM**	**10:30**	**5:00**	**11:00**
B Weight (g)	781	611	612	592	623
G Weight (g)	781	555	556	536	563
L Weight (g)	775	577	579	556	576

Table 4: Moisture content (% w.b.) of the rice throughout the drying process

Date	**Thurs. 4/30**	**Thurs. 4/30**	**Fri . 5/1**	**Fri. 5/1**	**Sat. 5/2**
Time	**11:30 AM**	**5:30 PM**	**10:30**	**5:00**	**11:00**
B (MC%)	32.5	13.8	13.9	11.0	15.4
G (MC%)	32.5	5.1	5.3	1.7	6.4
L (MC%)	32.0	8.7	9.0	5.3	8.5

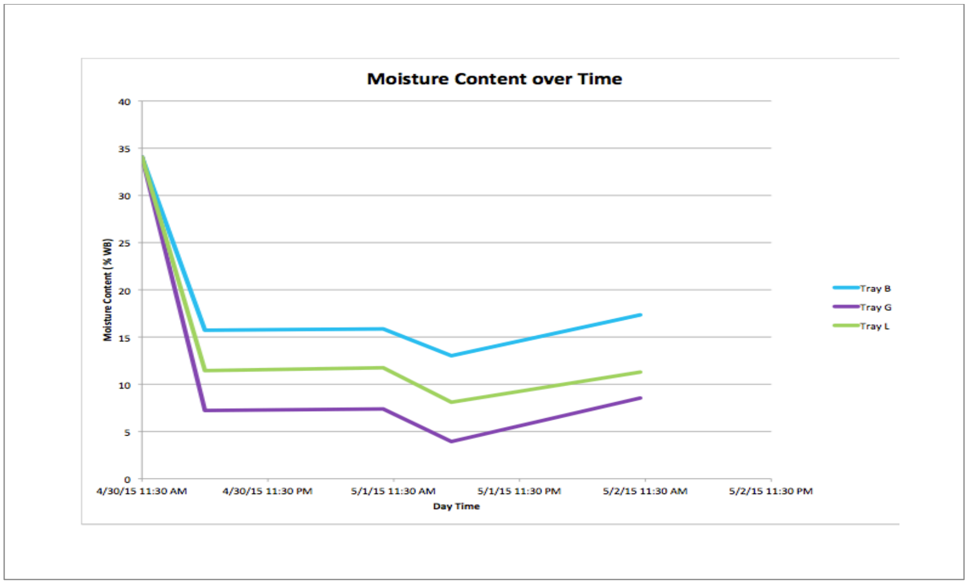

Figure 20: Rice moisture content over time. Tray B was at the top of the drying chamber, G was in the middle, and L was on the bottom of the chamber.

Observations:

The rice did the majority of its drying during the first day, it then reached its lowest moisture content at the end of the second day then it increased in moisture content over the last night. Tray G reached a moisture content of 5.1% by the end of the first day, putting it in the acceptable range.

We expected to see the highest final moisture content in Tray B, since it was the highest in the drying chamber, which we did. We expected to see the lowest moisture content in Tray L since it is the first tray the hot air interacts with. Instead we saw the lowest moisture content in Tray G. One reason the moisture content observed in tray G and L was different than we expected could be due to our tray set up. Tray G had a tray directly above it, which could have forced more air over the top of the rice, Tray L had a large gap between the rice and the next tray (figure 21). This difference in air movement could be the reason we saw this trend in moisture content.

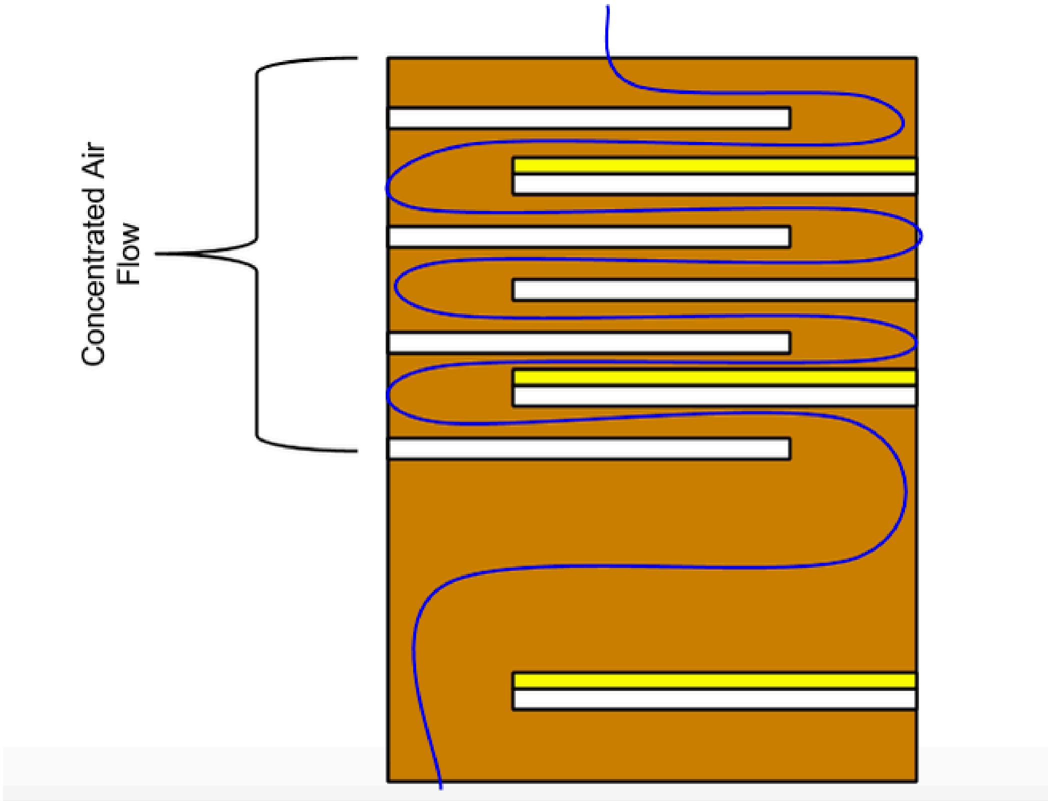

Figure 21: Diagram of the drying chamber set up. The yellow represents the rice, white represents the trays and blue represents airflow. The airflow was more concentrated above the G and L trays because of tray placement.

Conclusions

We observed some things we did not anticipate, an increase in moisture content the final night, the middle tray having the lowest moisture content and a large temperature difference between the top and bottom trays.

Dryer Experiment 2: Change in Rice Moisture Content

Overview

The second moisture content trial was executed the same way that the first trial was with a couple exceptions. First, four trays were loaded with rice rather than three. Second, all of the trays had a tray directly above them to in order to create a basis for comparison with the previous trial.

Results and Observations

The moisture content of four trays was measured over three days (figure 22). Like before, the moisture content had the most significant change the first day.

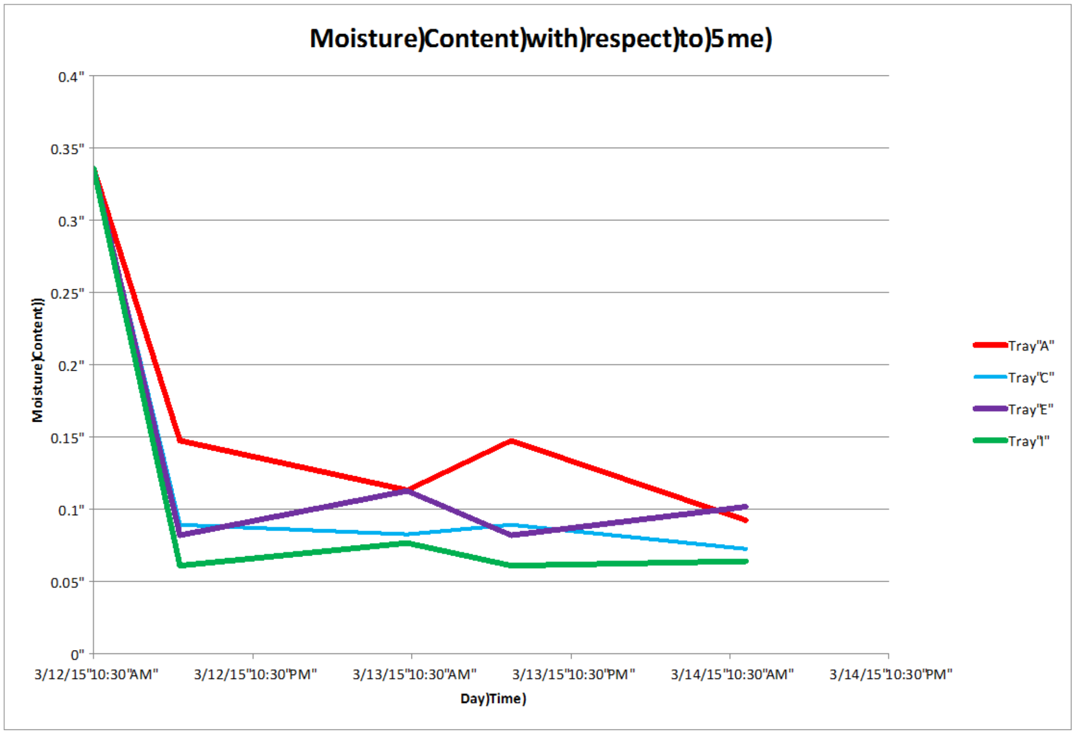

Figure 22: Moisture content of rice on four trays over three days.

The top tray (A) once again ended the first day with the highest moisture content out of all of the trays. The lowest tray, (I) was able to reach 6% moisture content at the end of the first day, within the acceptable range. The two middle trays (C and E) almost made it into the acceptable range, ending the first day with a moisture just 2% above the acceptable range at 8%.

Desiccant

The desiccant was placed in the dryer with wet rice to observe the effect the desiccant had on the rice and to monitor how the desiccant weight changed throughout the day and night. Two trays were loaded with wet rice and a third tray was loaded with desiccant on June 1st in the afternoon. The rice and desiccants were weighed before they were put into the dryer, after four hours in the dryer, and then again the next morning. The rice moisture content is plotted in figure 23.

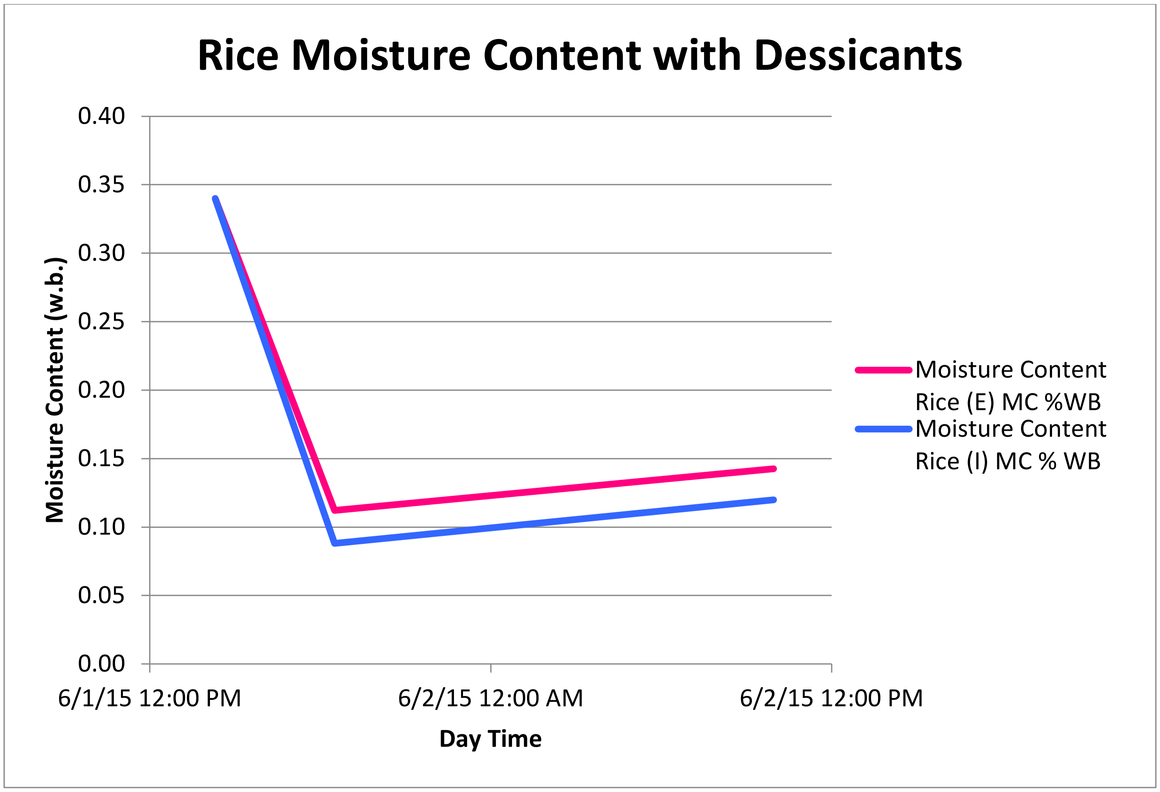

Figure 23: Rice moisture content over time with desiccants in the dryer

We expected the rice moisture content to remain constant or decrease during the night due to the desiccants. We believe this was not the observed trend for two reasons. First, the dryer was not sealed very well. Outside air was able to enter through the cracks between the door and the drying chamber, through the sides of the wood sealing the bottom of the chamber and through cracks where the vent doors met. Additionally, all of the desiccants were placed in the bottom portion of the drying chamber, rather than throughout and there wasn't that much of them.

On the other hand the desiccants reacted in a very positive manner during both the day and night. The weight change of the desiccants is plotted in figure 24.

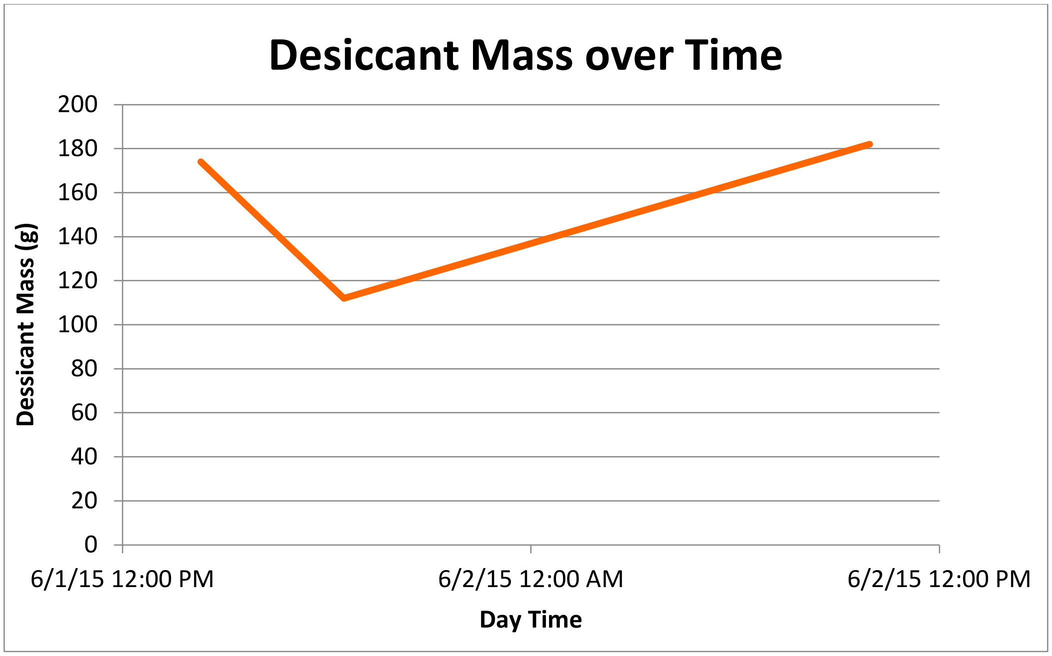

Figure 24: Desiccant mass over time when placed in the pollen dryer

During the day the mass of the desiccants decreased, this confirms that the dryer gets hot enough to recharge or dry the desiccants to prepare them for the night. The desiccants gained mass during the night. They were absorbing moisture from the air, but they did not have an effect on the rice either because of outside air entering the chamber or because they did not absorb enough moisture to prevent the rice from rehydrating.

Engineering Design and Product Development Process

Brainstorming and development of candidate solutions

The very first thing we considered when posed with the constraints of our project was zeolite beads. Initially we thought we could just throw those in with the pollen and the problem would be solved. We were connected with Jim Thompson and decided to consult him on the idea. He immediately suggested looking into desiccant salts over the beads. He pointed out that the beads were expensive, would be hard to get to Colombia and we would still be left with the issue of developing a heat source to recharge the beads. Desiccant salts on the other hand are inexpensive, accessible in Colombia and have a lower recharge temperature. After that conversation we naïvely thought we had found the solution to our project. We believed we could place the pollen in a large sealed oil can with desiccant salts and that alone would bring the moisture content down to 4-6%. After looking into different desiccants and ways to go about this, we realized that in order to recharge the desiccants we would need to create a solar dryer larger than the dryer we would need to build if we were drying the pollen alone. We started looking more seriously into the capabilities of solar dryers. After discovering the Appalachian State Solar Dryer and the Anna University Desiccant Integrated Dryer, we started figuring out how we could combine and modify the two designs to suite our pollen drying needs.

Engineering Constraints and Criteria

The goal of this design is to dry 30-40 kg of bee pollen per week collected by farmers in rural regions Colombia to prevent spoilage of the product.

There are several constraints and criteria in this particular bee pollen drying engineering problem. The dryer design cannot rely on on-grid electricity as it is expensive and unreliable in the region. The dryer also cannot exceed 50 C and must dry pollen within two days to preserve pollen quality. The dryer must cost less than $450 on the market. Below we have included a K-T analysis table showing various design criteria and their relative importance.

Table 5: K-T analysis of design criteria

Design Criteria	**Weighted Importance, Least Important (1) – Most Important (5)**
Dried pollen moisture content	5
Minimal moisture recharge post drying	4
Dryer Temperature of 50 C	4
High airflow	4
Robust design and construction	4
No use of on grid electricity	3
Pollen Capacity	3
Economics and Cost	4
Aesthetics	2
Ergonomics	3
Local Availability of Materials	4

For detailed descriptions of experimental protocols, results, and analyses, see the "Performance Evaluation and Final Design Product" section.

Project Schedules

As expected, the schedules created for this project were modified multiple times. The first schedule for winter and spring quarter was developed in December (figure 25), the schedule actually executed for winter quarter is shown in figure 26.

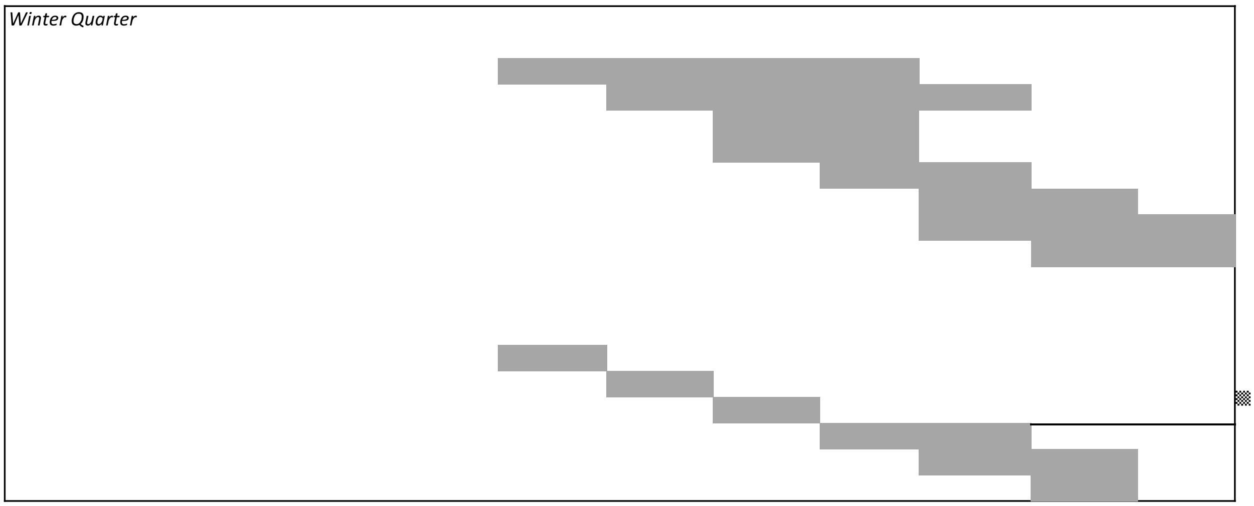

Figure 25: First full project schedule

MileStones	2015 Dec 1-15	Dec 16-31	Jan 1-15	Jan 16-31	Feb 1-15	Feb 16-29	Mar 1-15
Objective 1: Research pollen drying techniques that do not require electricity and preserve the nutritional characteristics of pollen.							
Task 1a: Aacquiring and characterizing the bee pollen				x	x		
Task 1b: Create a model for bee pollen by comparing with quinoa and pearl rice					x	x	
Task 1c: Research drying techniques and designing prototypes	x	x	x	x			
Objective 2: Create a value chain for bee pollen from hiive to market							
Task 2a: Evaluate pollen handling and storage techniques prior to dehydration				x	x		
Task 2b: Evaluate pollen handling and sotrage techniques after dehydrations				x	x		
Objective 3: Build multiple bee pollen dehydrator prototypes that operate without the use of on-grid electricity							
Task 3a: Order Parts				x	x	x	
Task 3b: Confirm work locations and acquire needed saftey training to begin buiilding				x	x		
Task 3c: Build prototypes based on designs in research stage					x	x	x
Objective 4: Evaluate the dried bee pollen produced by the prototypes for moisture content							
Task 4a: Test moisture content of dried pollen					x	x	

On Time Tasks	Unfinished Tasks
Late Tasks	New Task

Figure 26: The Winter Quarter Schedule Executed

The major items that shifted were building, testing, and modifying the prototype. We initially planned to have our first prototype built and tested within winter quarter, but due to the difficulty finding a work location, ordering materials, and finding people with the skills to help us construct the prototype, the dryer was only half built by the end of winter quarter. At this point we still had the intention to build and test multiple dryers. At the end of winter quarter we developed the spring quarter schedule (figure 27) where we planned on continuing to work on our prototype, build additional prototypes, build a full scale dryer, and then design a pollen storage system.

MileStones	2015					
	Mar 16-31	Apr 1-15	Apr 15-30	May 1-15	May 15-31	June 1-6
Objective 1: Optimize prototype performance						
Task 1a: Outline quantitative methods of measuring dryer performance (i.e. temperature and airflow with a given humidity and solar radiation)	x	x	x			
Task 1b: Test dryer performance in drying pollen and pollen model		x	x	x	x	
Task 1c: Evaluate drying performance of pollen during nighttime hours		x	x	x	x	
Task 1d: Resign dryer and repeat task 1a and 1b			x	x	x	
Objective #2: Build a full scale dryer prototype and test performance						
Task 2a: Scale up design of optimized prototype to build our final dryer prototype				x	x	
Task 2b: Test performance of prototype and present results at senior design showcase				x	x	x
Objective #3: Design a pollen storage system						
Task 3a: Design storage system based on literature research	x	x	x	x		
Task 3b: Test storage system with pollen dried by prototypes			x	x	x	

Figure 27: Spring quarter work plan outlined at the end of winter quarter.

This plan changed significantly through the quarter (figure 28). The partially built dryer wasn't moved out to the Western Agricultural Center, the location for final construction and testing, until April 7th. The dryer was completely built on April 9th. It was immensely more difficult than anticipated to gather all of the needed testing equipment and so the first drying test wasn't performed until week 5. Since testing didn't start until week 5 and a maximum of two tests could be performed per week. That left us with five more weeks to test and meant there wasn't time to fully evaluate out first prototype and then build more prototypes in addition to a full scale dryer, without sacrificing our understanding and the quality of our first dryer.

MileStones	2015					
	Mar 16-31	Apr 1-15	Apr 15-30	May 1-15	May 15-31	June 1-6
Objective 1: Optimize prototype performance						
Task 1a: Outline quantitative methods of measuring dryer performance (i.e. temperature and airflow with a given humidity and solar radiation)						
Task 1b: Test dryer performance in drying pollen and pollen model						
Task 1c: Evaluate drying performance of pollen during nighttime hours						
Task 1d: Resign dryer and repeat task 1a and 1b						
Objective #2: Build a full scale dryer prototype and test performance						
Task 2a: Scale up design of optimized prototype to build our final dryer prototype						
Task 2b: Test performance of prototype and present results at senior design showcase						
Objective #3: Design a pollen storage system						
Task 3a: Design storage system based on literature research						
Task 3b: Test storage system with pollen dried by prototypes						

Figure 28: Spring Quarter Schedule Performed (Green: on time tasks, Orange: unfinished tasks)

Budget

When we created our actual budget we had not yet chosen a dryer design. The budget we laid out included materials that were common to the majority of dryer designs (table 6). As a result of this our actual budget ended up costing less than our initial budget (table 7). The final budget is the amount it cost to build and test the prototype. Because our team was unable to determine how to expand the prototype into a full scale without compromising pollen quality, we were unable to determine the amount it would cost to build a full-scale dryer.

Table 6: Initial Project Budget Proposed December 2014

Bee Pollen Dryer Project Budget	
Duration: December 2014-June 2015	
Item	**Cost ($USD)**
Personnel	$0.00
Shop Labor	$0.00
Travel	$0.00
Equipment*	$0.00
Supplies/Materials	
Wood	$200.00
Aluminum	$60.00
Fan	$60.00
Heating Element	$60.00
Electrical Wiring	$30.00
Battery	$50.00
nails/screws	$20.00
Frozen/Fresh Bee Pollen	$100.00
Plexiglas	$45.00
Descant Beads*	$0.00
Mesh/Sieves/drawer	$30.00
Direct Costs	$655.00
Indirect Costs	$0.00
Total (Direct + Indirect)	$655.00

Table 7: Final Project Budget

Item	reason	Amount	Price per item	Recipt Total (price + tax)	Date Purchased	Place Purchased
4x8 - 3/4 ACX Plywood	Solar Dryer Frame	1	$ 50.40		2/28/2015	OK Lumber Company
4x8-1/2 Foil Faced OSB Radient Barrier (15/32")	Solar Dryer Frame	1	$ 20.40		2/28/2016	OK Lumber Company
				$ 70.09		
2x4-96" Premium KD whitewood stud	Solar Dryer Frame	2	$ 2.62		2/28/2015	Home Depot
CA Lumber Fee	Solar Dryer Frame	2	$ 0.02		2/28/2016	Home Depot
1x6-8ft Common Board	Solar Dryer Frame	6	$ 6.98		2/28/2017	Home Depot
CA Lumber Fee	Solar Dryer Frame	6	$ 0.06		2/28/2018	Home Depot
96"x27"x1/8" Metal Regular Lath	Solar Dryer Frame	6	$ 6.97		2/28/2019	Home Depot
R/O Auto High Heat Flat Black Spray	Solar Dryer Frame	4	$ 7.98		2/28/2020	Home Depot
Heavy Duty Tee Hinge Zinc	Solar Dryer Frame	2	$ 4.97		2/28/2021	Home Depot
6x1-1/4" Spax Multimaterial Fasteners 35 piece	Solar Dryer Frame	1	$ 1.94		2/28/2022	Home Depot
8x1-1/4" Spax Multimaterial Fasterners	Solar Dryer Frame	1	$ 7.98		2/28/2023	Home Depot
Titebond Ultimate Wood Glue	Solar Dryer Frame	1	$ 5.97		2/28/2024	Home Depot
4" Hook and Eye two pack	Solar Dryer Frame	2	$ 2.97		2/28/2025	Home Depot
				$ 166.77		
47 lb Basalite Portland Cement	Desiccant Mix	1	$ 7.99		2/09/2015	Davis Ace
				$ 8.67		
Cat Litter Ultra UNSC	Desiccant Mix	1	$ 11.49		2/09/2015	Petco
				$ 12.47		
Safeway Brand Sponges	Experiment Mtrls	1	$ 2.49		2/09/2015	Safeway
2 Anchor Glass Tupperware	Experiment Mtrls	1	$ 13.48		2/09/2015	Safeway
				$ 17.33		
Calcium Chloride	Desiccant Mix	1	$ 6.70		2/09/2015	Sierra Chemical Co.
				$ 7.24		
Vermiculite	Desiccant Mix		$ 6.44		2/09/2015	Ace Hardware
				$ 7.04		
Plastic Top	Dryer	1	$ 25.00		3/6/2015	Interstate Plastics
				$ 27.13		
Gala Apples	Drying Material	5 lb	$ 7.58			
Short Grain Rice	Drying Material	2.34 lb	$ 5.59	$ 13.17	4/27/2015	Davis Food Co-op
Glad Cling Wrap	Dryer	1	$ 3.99			
Ziploc Freezer Bag	Drying Matierlas	1	$ 4.99	$ 9.74	5/06/15	Safeway
		Total		$ 339.65		

Conclusions and Recommendations for Future Development

Conclusions

While this dryer is a good starting point for addressing the bee pollen-drying problem, it is not a complete solution. This dryer is able to bring the moisture content of the bottom tray down into the goal range of 4-6%, but it is unable to bring the moisture content of higher trays down into this range. This uneven drying is the main area that needs to be addressed. Luckily, we have lots of ideas of how modifications can be made to future prototypes to address the faults of our design as explained in the following section.

Recommendations for Future Development

The main areas that should be modified in future models are the drying chamber and the heating chamber.

First, the drying chamber seal needs to be improved in future models. Air was able to enter the drying chamber having detrimental effects to both day drying and night drying. For day drying, air entered the dryer through the spaces in between the chamber the door. As a result, the temperature difference between the top and bottom tray was able to reach upwards of 20°C. When the chamber was sealed, the maximum temperature difference observed was 11°C. This large temperature difference prevented the drying material in the top trays from reaching the six percent moisture content that the bottom trays were able to achieve.

At night, outside air entered the closed drying chamber through the poor bottom seal, the vent openings and once again, between the chamber and the door. This outside air increased the drying material's moisture content. Despite the desiccants pulling moisture from the air, too much air entered the chamber for the desiccants to stabilize or lower the drying material's moisture content.

The drying chamber could be further improved by increasing its insulation. As of now, wood is the only insulation in the chamber and so when the ambient temperature starts to drop, the internal temperature follows suite. Insulating the chamber would give the pollen a larger chance to dry via heat.

The heating chamber is the second main area that requires modification in future models. While the air in the drying chamber was able to consistently reach 50°C in Davis, the dryer needs to be able to reach 50°C in Colombia, where there is less solar radiation. Right now only the bottom of the heating chamber is lined with reflective material. One solution would be to also line the sides of the chamber with reflective material.

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