# Supporting Israeli Argan Agriculture by Improving the Argan Oil Production Process at Kibbutz Ketura

An Interactive Qualifying Project submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science

Written By Elise Deshusses and John Robinson
Submitted to:
Professor Isa Bar-On, Worcester Polytechnic Institute
Professor Seth Tuler, Worcester Polytechnic Institute
Sponsored by Nadav Solowey

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# Abstract

Most agriculture in southern Israel relies uniquely on the date palm. Argan trees are a possible new cash crop for the region due to their ability to thrive in the dry climate and the highly profitable argan oil. Kibbutz Ketura supports Israeli argan groves by buying their fruit to produce argan oil. Argan oil production, however, is a labor-intensive and under-developed process. We analyzed the process in Kibbutz Ketura to identify immediate and future improvements such that the process can expand to support Ketura's growing argan grove and other Israeli farmers. Using the results of this analysis, we implemented changes to the process to increase throughput.

# Acknowledgments

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# Key Terms

To prevent confusion when reading about the argan nut and its process we are beginning with this brief introduction to the vocabulary used to describe the various stages of the process.

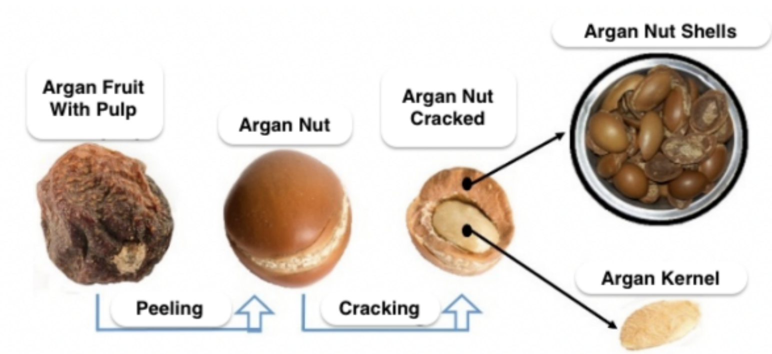
**Argan Fruit:** The fruit that comes off the argan tree, before it is peeled

**Peeling:** The process of peeling the pulp off the argan fruit until only the nut remains

**Argan Nut:** The hard inner shell and kernel of the argan fruit without the pulpy outer layer, after being peeled.

**Cracking:** The process by which the shell of the nut is separated from the kernel. This is typically done by slamming two plates of metal down on the nuts.

**Figure 1:** Labeled Argan Nut and Production Process (Rahib et al., 2019)




**Argan Shells:** The component of the nut that surrounds the kernel

**Argan Kernel:** What is contained within the argan shell. The kernel is where the majority of the oil is stored, which is the most profitable part of the fruit.

**Argan Oil:** Oil procured by pressing the argan kernel after it has been separated from the shell

# Chapter 1: Introduction

The argan fruit is a fruit that traditionally grows on wild argan trees in Morocco. When pressed, the kernel releases argan oil, an oil that is in incredibly high demand due to its many uses. By the end of 2025, the argan oil market is projected to be valued at $692.92 million USD ("The Global Argan Oil Market…," 2020), and the market's growth is expected to continue growing at an exponential rate (Fact.MR, 2021).

Argan oil is valued from $200 to $800 USD per liter based on quality (Solowey, N., personal communication, November 15, 2021) due to the many benefits of the oil. While research on the medical benefits of argan oil continues to grow, the oil has already been found effective in treating or preventing several medical conditions. Consuming argan oil can reduce the risk of heart disease and obesity by decreasing blood pressure (Berrougui et al., 2006), cholesterol, and triacylglycerol levels (Monfalouti et al., 2010; Ursoniu et al., 2018); (Derouiche et al., 2005). Other studies have found that argan oil has properties that suppress the growth of cancer cell lining in prostate cancer (Bennani et al., 2007) as well as in breast cancer cells (Babili et al., 2010; (Bouyahya et al., 2020) and melanoma cancer cells (Bourhim et al., 2021; Villareal et al., 2013).

There is also growing demand for argan oil in the cosmetic industry, which can be attributed to many health and beauty magazines that claim argan oil products are the "miracle oil" in "many products that promise hydration or anti-aging properties" (Foussianes & Tonelli, 2021). The cosmetic industry's claims about argan oil are supported by several studies. One study found argan oil can help maintain skin elasticity when aging (Qiraouani Boucetta et al., 2015), while another found that mixing shea butter and tea tree oil into argan oil is hydrating and healing for skin wounds (Costa-Fernandez et al., 2021).

Most argan is grown in Morocco; in fact, Morocco accounts for 99% of the global argan market. The Moroccan process is incredibly labor-intensive and traditionally done by Moroccan women. With these methods, it takes one woman twenty hours to produce one liter of oil (Ash, n.d.). This process is not efficient or scalable and cannot meet the growing demand for argan oil. In southern Israel, a small Kibbutz is exploring innovative methods of argan oil production to attempt to bring Israel into the argan market. At Kibbutz Ketura, a desert community in southern Israel, sixty-seven argan trees were planted in 1985 (E. M. Solowey, 2001). These trees were planted on the kibbutz because of their potential solution to a growing challenge for agriculture in the southern desert region of Israel. Kibbutz Ketura, as well as other agricultural groups in the region, are currently reliant primarily on the date palm. While the date palm is a very profitable plant, this makes the kibbutz reliant on a single crop, which would be devastating if something happened to the date palm, such as a change in global demand for dates or a disease that targets date palms. They also require large amounts of water, an average of 850 liters per day (Solowey, N., personal communication, February 21, 2022). Argan trees, on the other hand, require an average of 50-80 liters per day, far less than the date palm (Solowey, N., personal communication, February 21, 2022).

On Kibbutz Ketura, Nadav Solowey has created a process to produce oil from the argan kernel more efficiently than Moroccan methods. While there are a number of groups beginning to produce argan fruit in Israel, there are only four locations in Israel that produce argan oil, and only two of those are willing to purchase nuts from growers (Solowey, N., personal communication, February 21, 2022). The continued improvement and success of the process at Ketura allows the kibbutz to purchase more argan fruit, allowing for the continued development of the argan industry in Israel.

Solowey is scaling up his process to protect argan production and to reach his goal of Israel eventually controlling 1% of the worldwide argan market. The process can currently only process 175 kilos of fruit per week, which is approximately 220 liters of oil per year. In five years, Solowey would like to be able to produce 250 liters of oil per week. Our project's goal was to analyze the process' scalability and address the main inefficiency through implementing changes. We considered many components of the process to identify portions of the process that should be improved now and in the future.

# Chapter 2: Background

## 2.1 Importance of Argan Oil Production to Israel

Diversity makes an ecosystem resilient to changes in the environment. This is related to the diversity-stability hypothesis, the theory that increased diversity adds layers of redundancy to the system (Kerr, J. T., 2014). In the event of a change in the environment, whether that be a new disease or a change in the local climate, systems with more diversity are more likely to survive as they are more likely to have a breed that can withstand the environmental change. The opposite of a diverse system in agriculture is a monoculture. A monoculture is an agricultural industry that is reliant on a single type and breed of plant, as is the case with the banana industry. The banana industry is currently reliant on the Cavendish banana as it tastes better and produces more fruit than other banana breeds. A disease that targets Cavendish bananas, referred to as TR4, was first detected in Asia in the 1990s. This disease is destroying banana farms and is projected to destroy Cavendish banana farms across the globe when it reaches Latin America (Butler D., 2013). This type of destruction is more likely in a monoculture as the lack of diversity makes the system less resilient.

Southern Israeli agriculture is also a monoculture, relying almost solely on the Medjool date palm. This means that if something happens to the Medjool date palm, it will be devastating to local agriculture. Relying on this monoculture not only makes date farming vulnerable to disease and changes in climate but also the global date market. Being reliant primarily on dates also makes the income of date farmers directly tied to the global demand for dates. While the global date fruit market is not expected to change drastically in the near future, being reliant on multiple plants makes Israeli agriculture more resilient to unexpected changes.

To make Israeli agriculture more resilient, a new crop is needed that is well situated for the Israeli climate. The Israeli climate imposes two major factors; There is a lack of water, and what water is available has a high salt content. The argan tree is uniquely situated for the Israeli desert in that it can be watered with saltwater and only requires at most 80 liters per day compared to the 850 liters per day of the date palms (Nerd et al., 1994). Identifying argan as a possible solution to Israel's agriculture problem, argan clippings were brought from wild trees in Morocco to Kibbutz Ketura (E. M. Solowey, 2001). Clippings from these trees were then planted at various groves around Israel.

## 2.2 Current State of Argan Oil Production in Israel

Currently, there are 300 dunams producing argan fruit in Israel, with 200 more anticipated to produce fruit in the next two years. Most argan growers, however, do not have the ability to produce oil from their fruit; in fact, there are only four facilities to produce argan oil in Israel, three of which are currently in use (Solowey, N., personal communication, February 21, 2022). Only two of these facilities will buy fruit from argan growers, making it difficult to sustain an argan grove.

Solowey calculates that to sustain an argan grove, the fruit must be sold for at least 5 shekels per kilo. Solowey is committed to purchasing argan fruit for this price so as to support Israeli argan groves. Solowey has already saved one argan grove this way, but Israeli argan groves are beginning to be pulled out as growers realize they will not be able to make a profit (Solowey, N., personal communication, February 21, 2022).

There is currently not enough argan oil production in Israel to sustain the number of argan groves that have been planted and are anticipated to begin producing fruit. This surplus of fruit leads to decreased fruit prices and growers being unable to support their farms. Improving the throughput of the process at Ketura will allow Solowey to support more Israeli argan growers, allowing argan groves to become an Israeli cash crop (Solowey, N., personal communication, February 21, 2022).

## 2.3 Current Production Process in Kibbutz Ketura

To produce oil from argan fruit, the process used in Ketura is divided into ten steps.

**Figure 2: Modified Potato Peeler**

(a) The process begins with the argan fruit being placed into a modified potato peeler. Within the peeler, the fruit encounters a coarse spinning disc that pulls the skin off of the argan fruit.

**Figure 3: Nuts Sorting Sifter**

(b) The peeled nuts are then put into a sifter to sort them by size. This is important for two reasons: 1) the nuts need to be cracked from smallest to biggest, and 2) the larger nuts are more difficult to crack, often needing to be put into the cracker two or three times. The rudimentary sifter Ketura is using involves a series of crates with appropriately sized holes to sort the nuts into four groups: small, medium-small, medium-large, and large.

**Figure 4: Cracking Machine**

(c) The nuts are placed in the cracking machine from smallest to largest. In the cracking machine, the nuts will encounter two metal plates spinning in opposite directions that are moved farther apart as the nuts are cracked. The smallest nuts are cracked first, with the plates fairly close together. As the plates are moved farther apart by the operator, the larger nuts fit between the plates and are then cracked.

**Figure 5: Post-Cracking Sifting**

(d) Following the cracking, the mixture of kernels and shells is placed into another rudimentary sifter. This sifter has two purposes. First, the sifter is used to remove large pieces of shell that often contain air bubbles. This is what allows the next stage of the process, the density separation using saltwater, to function. Second, the use of this post-cracking sifter is to remove very small pieces of dust. Large amounts of argan dust will make the saltwater cloudy and difficult to work with, thus shortening the life of the saltwater.

**Figure 6: Salt Water Density Separator**

(e) With the large shells and dust sorted out, the mixture is placed into a saltwater bath. The majority of argan shells are denser than the majority of argan kernels. This means that when placed in the saltwater of the appropriate salinity, kernels will float, and shells will sink. The mixture that is mostly kernels at the top of the water, referred to as the kernel mixture is then soaked in fresh water and set out to dry. The shell mixture, the pieces that sink in the saltwater, are soaked and dried as well. Ketura has traditionally used bowls for saltwater separation that can only handle three hundred grams of argan nuts at a time, meaning that this process is very time-consuming and labor-intensive.

**Figure 7: Drying Shells**

**Figure 8: Kernel Mixture**

**Figure 9: Argan press**

(f) The Kernels and Shells are placed on a screen to dry. It usually takes about one day to dry.

(g) The kernel mixture will contain some shell pieces, and the shell mixture will contain some kernel pieces. These defects are sorted through as it is not ideal for the argan shell to be pressed in the oil press. While this process is labor-intensive, it is significantly faster than separating all of the kernels by hand, as Ketura did before implementing the saltwater density separation.

(h) When producing edible oil, the kernels are roasted. It generally takes about 40 minutes to roast one kilo of kernels.

(i) The kernels are put into a press, where the oil they contain is squeezed out of them.

**Figure 10: Pure Oil Separating**

(j) The oil that comes out of this pressing process is placed in jars and allowed to sit for one to two weeks in order to let small pieces of argan dust separate out, leaving pure oil behind.

While this process is more efficient than cracking and sorting by hand, as is traditionally done in Morocco, it is not efficient enough to process large quantities of argan oil. For Ketura to be able to produce enough oil to support their own expanding argan grove as well as groves throughout Israel, this process needs to be able to produce oil far more efficiently and require far less labor time.

# Chapter 3: Methods

The goal of the project is to support Israeli argan agriculture through improving and expanding the argan oil production process at Kibbutz Ketura in the Arava Valley. To improve the production process, we evaluated the current state of the argan oil production process at Kibbutz Ketura, addressed the main inefficiency by implementing changes and outlined future areas of improvement. First, we had to collect data on the current process and analyze the data to address these objectives. To achieve our goal, we did the following:

1. Evaluated the current process and its scalability
2. Improved the process though implementing immediate changes
3. Identified areas for improvement of the future process

To fully understand and evaluate the argan oil production process, we collected and analyzed data on various parts of the process. Masses were measured using a metric kitchen scale that is accurate to the gram. The dimensions of the nuts were measured using a pair of standard manual calipers, which are accurate to the two-tenths of a millimeter. The duration of tasks was measured using a phone timer app and the lapping function.

Random samples were collected after mixing the total population in a large tray. A cylindrical cup was pushed downwards in the tray to take a vertical 'slice' of the total population. This method was used to account for the natural tendency of smaller pieces gravitating towards the bottom and larger pieces towards the top.

## 3.1 Analyzing the Labor Time in Relation to the Quantity of Nuts

### 3.1.1 Cycle Time

Cycle time can be used to estimate a process' maximum possible production, which gives insight into the capacity of the process. The cycle time represents the time it takes for an entity or group of products to pass through a system. Typically, the quicker the cycle time, the more efficient the process. We measured the time required to complete tasks in the sub-processes in the system, along with the quantities of nuts being processed. With the data collected, we found the average of each task and then of each sub-process.

### 3.1.2 Throughput

The throughput of a system is the quantity of product outputted by the system in a certain period of time. This statistic represents the rate of product produced, which is an important metric in increasing efficiency and measuring changes in a process. We determined the throughput by calculating the average time to produce 1 liter of argan oil.

### 3.1.3 Process Capability

Traditional process capability metrics require a process to be fully standardized and statistically 'in control' or predictable. Since the current argan oil production process is not fully standardized and the variation in the process has unpredictable and out-of-control variation, we measured the capabilities of the process through non-traditional methods.

We calculated the process capabilities as a series of metrics, which included the total yield of argan oil for inputted argan fruit and the maximum amount of argan fruit that can be processed based on the limiting factor of labor time available and cycle time. The total percent of outputted oil from inputted fruit was calculated by multiplying the individual process success rates to find the total success rate of the process.

These metrics allow us to understand what the process is capable of and how effective it is at extracting the maximum amount of oil.

## 3.2 Analyzing the Effectiveness of the Pre-Cracking Nut Size Groups

We measured the nut sizes and distribution of nut size groups in the cracking process to learn about the pre-cracking and cracking process. By measuring the dimensions of nuts from each of the size groups and measuring the uncracked nuts, we analyzed the distributions of sizes between the cracked and uncracked nuts. By graphing this data on frequency diagrams, we were able to determine how successful the pre-sorting process is in sorting the nuts by size. We calculated the ranges and types of distributions based on the nut lengths and the smaller of the two widths.

## 3.3 Analyzing the Density of Nut Pieces for Better Saltwater Separation Salinity

By calculating the densities of the kernel pieces and shell pieces that go into the saltwater bath, we were able to determine an optimal level of salinity for separating the mixture with minimum defects. To get the densities, we measured the masses of ten dry samples of kernels and shells from the kernel mixture. We then measured the water displaced by the kernel pieces and shell pieces in a graduated cylinder. Later, we selected ten random samples of shells from the sinking shell mixture in the saltwater separation and measured their masses and volumes in the same fashion.

Using this data, we were able to calculate the optimal salinities for the saltwater. Determining the optimal salinity is important because it can help decrease the number of kernels sinking in the bath and the number of shells floating with the kernels. In other words, it helps to improve the effectiveness of the separation process.

## 3.4 Assessing the Current Process Sensitivities

We conducted a sensitivity analysis to assess how the different variables affect the production of argan oil. Understanding the effects on argan oil production is important because it can help avoid or prepare for potential bad outcomes and focus on the more impactful parts of the process. Furthermore, since the current process has uncertainty concerning the volume of argan fruit produced, considering different outcomes can help predict argan oil production.

We collected data on the yearly mass of argan fruit that is currently being processed and the amount of labor time available. Using statistics about the argan fruit and the production process, we calculated the labor required, resources required, volume of oil produced, and the total estimated profits.

## 3.5 Assessing Process Scalability Over the Next Five Years

We conducted a scenario analysis to assess the feasibility and possible outcomes of different future scenarios. We considered three scenarios that may occur over the next five years and analyzed the profits and volume of argan oil outputs. The base scenario represents expected production growth while the low scenario represents a poor situation, and the high represents an optimistic situation. The analysis helps show how the different variables affect the production of argan oil over time. Understanding the effects on argan oil production is important because it can help focus on the more impactful parts of the process and prepare for or avoid potential bad outcomes. Furthermore, considering different outcomes can help predict production with a margin of error since the current process has uncertainty concerning the volume of production. Lastly, these scenarios can help predict if or when it would be beneficial to invest in expensive, fully automated machinery.

To conduct the analysis, we came up with a set of assumptions and collected data on the annual mass of argan fruit currently being processed and labor time available. We also collected data on the costs of the process and the expected growth in oil production.

# Chapter 4: Results

First, we determined that the main bottlenecks in the process were the saltwater separation process and the manual sorting steps surrounding it. Then, we discovered that since the process was not standardized, a majority of production labor time went into non-value-added setup and transportation tasks. In analyzing the data with costs and future estimations, we found the extraordinary profitability of argan oil. Using densities of argan parts, we calculated the ideal salinity for minimizing defects in the saltwater separation. Lastly, we created a set of tools to improve and simplify the saltwater separation process, which will help increase the volume of nuts the process can handle.

## 4.1 Process Analysis

### 4.1.1 Analysis of Labor Time in Relation to the Quantity of Nuts

Cycle time is the time it takes for an entity or group to pass through a task or process from start to finish. Since the argan oil production process is made up of many smaller processes, there are many shorter cycle times that make up the entire system cycle time. Cycle time is a good metric in measuring the time it takes to make a product from beginning to end.

The production process typically uses batch sizes of 10 kg or 20 kg of fruit. In the case of an 11 kg batch of argan fruit, as shown in Table 1 below, the argan oil production process cycle time total is estimated to be 205 minutes, or 3 hours and 25 minutes (see **Appendix A** for full list of cycle times). It should be noted that the process for cosmetic oil does not include roasting the kernels and thus has a cycle time of 183 minutes. However, for both edible and cosmetic oil, these cycle times only include the typical tasks done during each step of the process while the majority of the setup, clean up, and transportation times are unaccounted for. Solowey reports that it typically takes 10 hours of labor time to produce one liter of argan oil.

Since the process is not standardized and is relatively slack in terms of timing, the process times are inconsistent, and cycle times have great potential to vary. That being said, the throughput of the current process with 20 to 25 hours of labor time is 2 liters of argan oil per week.

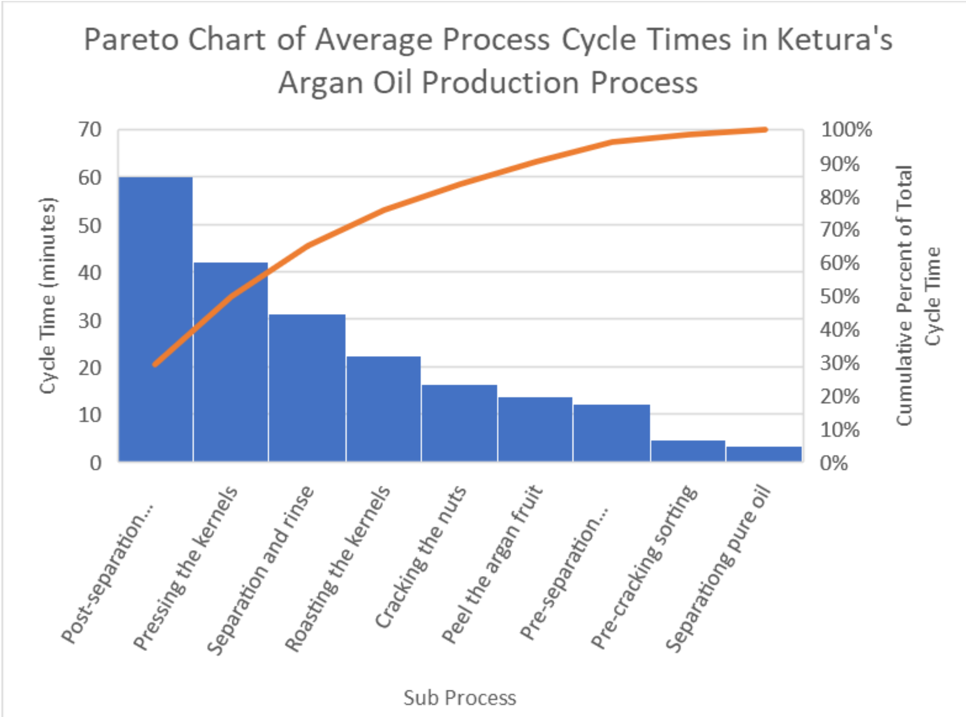



Figure 11. Pareto Chart of Average Process Cycle Times

Table 1. Cycle Times for Each Production Sub-Process When Batch Size is 11 kg

| **Sub - Process** | **Time (minutes)** |
|---|---|
| Peel the argan fruit | 13.8 |
| Pre-Cracking sorting | 4.6 |
| Cracking the nuts * | 16.3 |
| Pre-separation sorting | 12 |
| Separation and rinse | 31.2 |
| Drying kernel and shell mixture ** | *1 day* |
| Post-separation sorting | 60 |
| Roasting the kernels *** | 22.3 |

| | |
|---|---|
| Pressing the kernels | 42.0 |
| **Total** | **205.5** |

* Total time for all nut size-groups. Time and success rate varies a lot by nut size-group
** Not a cycle time that requires labor
*** Roasting the kernels is only applicable when producing edible argan oil

As can be seen in Table 1, the longest cycle time is that of the post-separation sorting, which is a fully manual step and takes 60 minutes per kilo. It should be noted that the pre-separation sorting, separation and rinse, and post-separation sorting could be counted as a single sub-process. However, since this is a lengthy process and requires about one day of drying time after the saltwater separation, we decided to break it up into several processes. Looking at the table, we observed that these three sub-processes take one hour and 43 minutes of labor time.

### 4.1.2 Process Capability

Each process in the argan oil production process has a certain percentage of bad nuts, lost kernels, or other defects. For example, when peeling the argan fruit, 10% of the fruit are peeled unsuccessfully, and about ten fruit per 10 kilos are found in the peel waste. These defective rates may seem negligible when looking at each individual process, but when the defects compound process after process, the total output yield can be greatly affected.

Table 2 below shows the percentage of product conserved for each of the processes as well as the total product conserved. Peeling the argan fruit and pressing the kernels both have conservation rates of 90%, which means 10% of the available goods are lost to defects. The total production process conservation rate is 73% which means that of the amount of oil in the kernels at the start of the production process, 73% of it is extracted and collected.

Table 2. Individual and Total Percentage of Product Conserved for Sub-Processes in the Oil Production Process

| Sub - Process | Percentage of Product Conserved |
|---|---|
| Peel the argan fruit | 0.9 |
| Pre-Cracking sorting | 0.99 |

| | |
|---|---|
| Cracking the nuts * | 0.959 |
| Pre-separation sorting | 0.99 |
| Separation and rinse | 0.98 |
| Post-Separation sorting | 0.98 |
| Drying the kernels and shells | 1 |
| Roasting the kernels | 1 |
| Pressing the kernels | 0.9 |
| **Total** | **0.73** |

When considering the two main limiting factors, the available labor time and cycle time, the process is highly restricted in production. First, the process is currently producing at maximum capacity in terms of labor time. The weekly available labor time is 20 to 25 hours, and the process is currently operating on 20 to 25 hours of labor time per week. Second, the cycle time is around 10 hours per liter; however, the longest sub-process cycle time is 60 minutes, meaning a new batch could be started every 60 minutes for a continuous batch process. With unlimited labor time and materials, the process could theoretically produce up to 40 liters of argan oil per week with ten full-time workers.

### 4.1.3 Nut Size-Groups and Cracking Success

The cracking machine, as seen in Figure 4, cracks the nuts using two spinning plates with a distance between them which can be adjusted to the best height for cracking specific sizes of nuts. For each set of nuts of a certain size, the machine can be adjusted to the best height between the two plates to successfully crack the set of nuts.

We measured the lengths, larger widths, and smaller widths of nuts for each size group and plotted the distributions. Figure 12 below shows a distribution of nut lengths for each of the four size groups from a batch of nuts that were grown on the kibbutz six years ago.

It is clear that there is a significant overlap in nut lengths by size groups. On the other hand, in Figure 13, there seems to be less overlap in shorter nut widths by size group. The distribution for the lengths of the medium-large and large size groups appear to have a similar center. However, the smaller widths of the medium-large size group clearly have a different center with a more narrow distribution than the large nut size group.

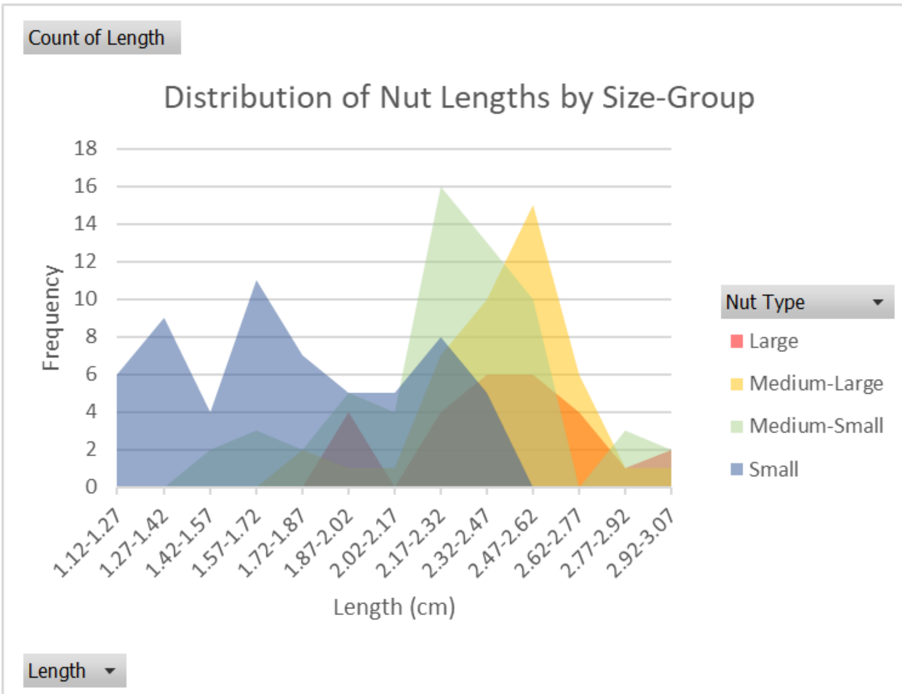



Figure 12: Plot of the Distribution of Nut Lengths by Size Group for a Five Kilo Batch of Kibbutz Ketura-Grown Argan Nuts From 2016

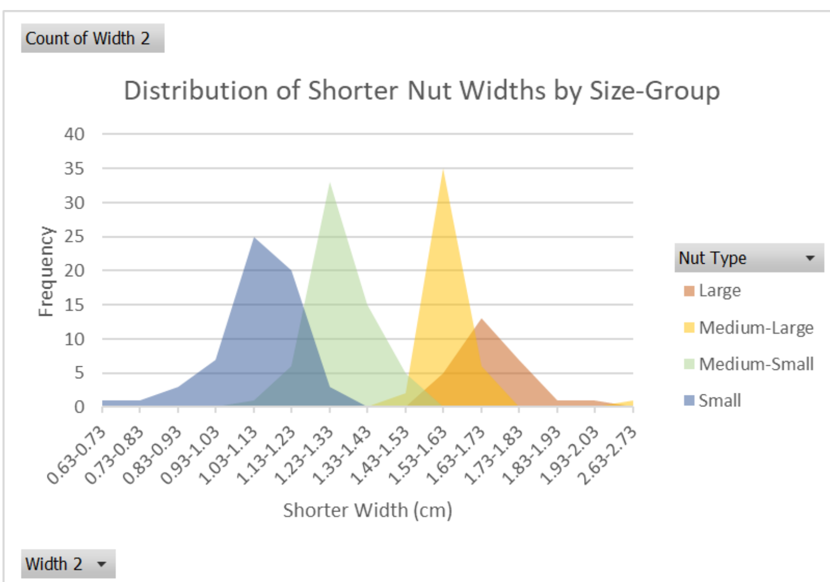



Figure 13. Plot of the Distribution of Nut widths by Size Group for a Five Kilo Batch of Kibbutz Ketura-Grown Argan Nuts From 2016

When plotting the distribution of cracked and uncracked nuts for each size group, it is clear that unsuccessfully cracked nuts in the small and medium-small size groups tend to have larger lengths and widths (see **Appendix B** for all distribution plots). This can be observed in Figure 14 and Figure 15 for the small nuts below.

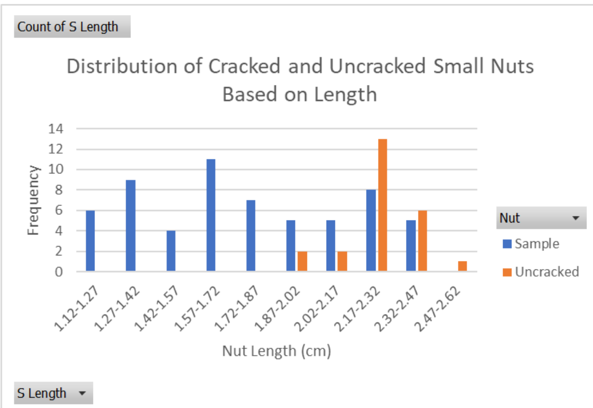



Figure 14 Distribution of Small Nut Lengths for Cracked and Uncracked Nuts

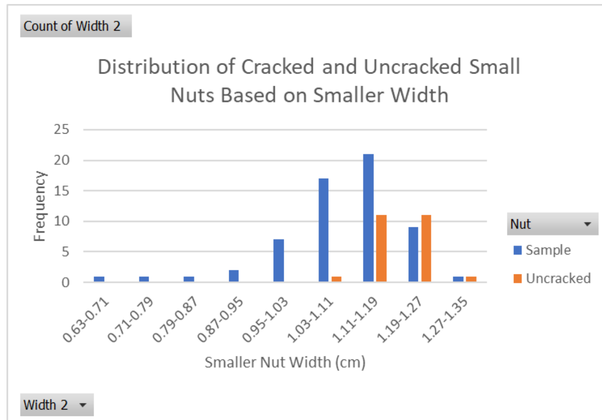



Figure 15. Distribution of Small Nut Widths for Cracked and Uncracked Nuts

When observing the medium-large and large nut size groups, the distribution of cracked versus uncracked nuts is less distinct. While the distribution of the size-group lengths and widths are roughly unimodal, the distribution of the uncracked nuts is more spread or uniform (Figure 16 and FIgure 17). It should be noted that the number of nuts in the medium-large and large groups was significantly less than for the two smaller-sized groups, which could have affected the larger sizes' cracking success.

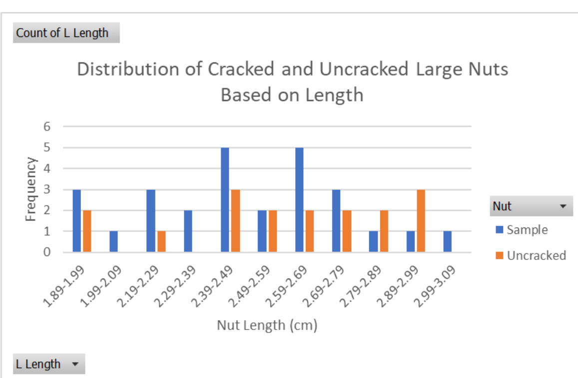



Figure 16. Distribution of Large Nut Lengths for Cracked and Uncracked Nuts

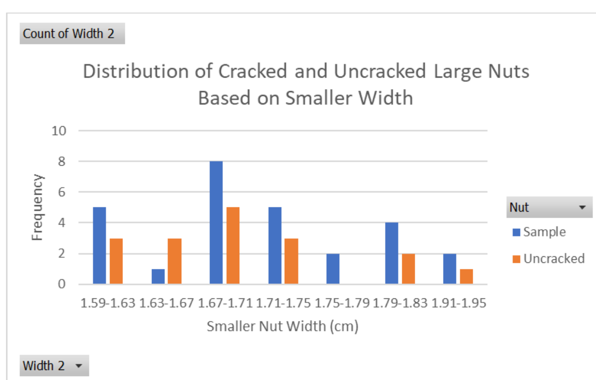



Figure 17. Distribution of Large Nut Widths for Cracked and Uncracked Nuts

A satisfactorily cracked nut is a nut that is cracked so that it exposes all of the nut's kernels in a way such that the kernels are or will be released with gentle mixing. Using these standards, the highest success rate was that of the small nut group, followed by the medium-small group, medium-large group, and finally the large size group. Small nuts and medium-small nuts were the most successfully cracked nut groups at 98% and 96%, respectively. On the other hand, medium-large and large nuts did not have satisfactory success rates at 59% and 37%, respectively. The proportions of cracking success by nut size group are shown in Table 3 below.

Table 3. Cracking Success by Nut Size-Groups

| | **Small Nuts** | **Medium-Small Nuts** | **Medium-Large Nuts** | **Large Nuts** | **Total** |
|---|---|---|---|---|---|
| **Count** | 1284 | 1169 | 44 | 27 | 2524 |
| **Defect count** | 24 | 45 | 18 | 17 | 104 |
| **Success Rate** | **0.98** | **0.96** | **0.59** | **0.37** | **0.96** |

### 4.1.3 Analyzing the Argan Density and Salinity of the Saltwater Separation

To determine an optimal salinity for the saltwater separation, we measured the densities of the separated kernels and shells. The average density of the kernels was 0.988 g/mL. The density of the shells that floated and were collected with the kernels in the saltwater bath was 0.928 g/mL. Lastly, the density of the shells that sunk to the bottom of the saltwater bath and were collected after the kernel mixture was removed was 1.170 g/mL. It should be noted, however, that this represents the measured densities of the dry components. As the kernels sink in fresh water (1 g/mL), this shows that the kernel and shells absorb water, increasing their density, and sinking. We anticipate the amount of water the kernels and shells absorb to be similar, and thus the measurements of the dry densities to still represent the relative densities of the components, if not the specific densities of the components.

Table 4. Densities of Kernels and Shells

| Density of Pure Kernels and Shells | | | |
|---|---|---|---|
| | Kernels | Floating shells | Sinking shells |

| | | | |
|---|---|---|---|
| Average Density (g/mL) | 0.988 | 0.928 | 1.170 |

The following table shows the density of a saltwater solution based on the mass of salt for one liter of desalinated water. The salinity saturation percent is shown in the right column for room temperature water (24 degrees celsius).

Table 5. Mass of Salt per Liter of Water for Various Density and Salinity Levels at Room Temperature

| **Salt (g)** | **Density (g/mL)** | **Salinity (%)** |
|---|---|---|
| 0 | 1.000 | 0.00% |
| 115 | 1.115 | 32.39% |
| 130 | 1.130 | 36.62% |
| 141 | 1.141 | 39.72% |
| 172 | 1.172 | 48.45% |
| 180 | 1.180 | 50.70% |

The table below shows data we collected on ten random samples of kernel mixture after the saltwater separation process. About 17.2% of the kernel mixture is shells and needs to be manually removed in the post-separation sorting process.

Table 6. Percent of Shell Defects in Kernel Mixture After Saltwater Separation

| Sample | Mass of kernels (g) | Mass of shells (g) | Percent defects by mass (g) |
|---|---|---|---|
| 1 | 42 | 8 | 0.160 |
| 2 | 44 | 7 | 0.137 |
| 3 | 41 | 9 | 0.180 |
| 4 | 43 | 8 | 0.157 |
| 5 | 44 | 6 | 0.120 |
| 6 | 41 | 9 | 0.180 |
| 7 | 36.5 | 13 | 0.263 |

| | | | |
|---|---|---|---|
| 8 | 42 | 8 | 0.160 |
| 9 | 41 | 9 | 0.180 |
| 10 | 41 | 9 | 0.180 |
| **Average** | **41.55** | **8.6** | **0.172** |

### 4.1.4 Sensitivity Analysis on the Current Process

The sensitivity analysis considered three scenarios: base, low, and high. The following assumptions were made to analyze the general situations and specific situations.

[ Information Redacted to Preserve Best Interests of Project Sponsor ]

### 4.1.5 Scenario Analysis for Future Situations

The scenario analyses for the next five years were conducted with the following general and situation-specific assumptions.

[ Information Redacted to Preserve Best Interests of Project Sponsor ]

## 4.2 Exploring Alternative Separation Techniques

Following the throughput analysis of the process, it is clear that the saltwater separation was the largest bottleneck in the process. The saltwater separation had two main issues: effectiveness and labor time. The process is inaccurate as 17.% of the resulting kernel mixture are shells and 2% of the resulting shell mixture is kernels. This is too many defects to warrant not sorting through the kernel or shell mixture, and there may not be a way to make this saltwater separation more accurate. As the process scales, the percentage of these defects will likely stay the same, leading to more labor time lost in this quality control step. The process was also labor-intensive as the saltwater bath was only able to handle batches of three hundred grams of argan mixture. To process the anticipated batch sizes of five to twenty kilos of argan mixture, the batches would have to be split into between sixteen and seventy groups to be separated with this saltwater separation process. Processing one group of three hundred grams takes 5 minutes, and processing one bath of five kilos would take an anticipated 62 minutes. These issues with the saltwater separation technique warranted research into alternative separation techniques that may be more effective.

### 4.2.1 Researching Relative Separation Techniques

There are many devices that are used to separate other kinds of nuts that, through some adaptation, could become effective at separating argan nuts. These other sorting techniques can be classified into kinematic separation and optical separation. Kinematic separation is the process through which components are brought up a ramp, shaken, and pushed by specifically calibrated air currents (Gravity Separators | Dry Separation Equipment Manufacturer, n.d.). This moves the lighter component down the ramp and the heavier component up the ramp. This has some potential at being effective with argan nuts, although the high variation between the size and shape of each nut may make this likely unfeasible. The other applicable method is optical separation. Optical separation is the process of using computer vision to identify differences in color and shape. These separators are used in similar use cases for almonds, walnuts, and coffee beans (Sun, 2016). An optical separator has the potential to reach a 99.9% success rate for separation, making it an ideal separator. The optical separator, however, is priced close to NIS 930,000, making it infeasible for the current scale of the process at Kibbutz Ketura. Saltwater separation is the clear solution for Ketura's process until an optical separator is financially feasible.

### 4.2.2 Improving Salt Water Separation

Although salt water is the ideal separation technique for the current process in Ketura, the process needs to be less labor-intensive to support the scaled process. To reduce labor time, we created a larger saltwater basin to handle larger batch sizes. Our basin can handle batch sizes from 4.7 kilos to 15.6 kilos such that it can be effective for both the small quantities of nuts Ketura is currently handling as well as larger quantities of nuts they intend to handle in the future.


**Figure 18: Salt Water Basin**
See **Appendix C** for diagrams

A larger basin also requires larger tools to make the basin work effectively. We created baskets sized to the basin to collect the kernels and the shells. Once separated, the mixtures also need to be soaked in freshwater. To allow these larger tools to be soaked, we also created a larger freshwater basin. This freshwater basin also allows the freshwater to be reused between batches.

**Figure 19: Fresh Water Basin**
(See **Appendix D** for diagrams)

To dry the argan pieces, we intend to continue using the same method Ketura currently employs, putting the mixture onto a window screen that is suspended off the ground. This allows the nuts to dry and spreads the mixture out, allowing for a final manual sorting step to remove kernels from the shell mixture and shells from the kernel mixture.

# Chapter 5: Discussion

## 5.1 Effects of Implemented Changes

### 5.1.1 Standardizing the Process and Salt Water Salinity

Standardization is an important characteristic in manufacturing processes because it increases consistency and decreases variation throughout the process. When a process is not standardized, there is room for unpredictable errors, and the process is difficult to measure and analyze statistically for improvement.

While the current argan oil production process at Ketura is methodical, it is not a standardized process. For example, most batch sizes in the sorting, sifting, and pressing processes are done by eye and vary based on the operator. The salinity of the solution in the saltwater separation is estimated at around 60-70% saturation, but the actual quantity of salt in the solution is unknown. Additionally, in the saltwater separation process, we observed that sometimes the kernels and shells are more thoroughly rinsed before putting them in the freshwater bath, while other times they are thoroughly rinsed after the freshwater bath. In this example, standardizing the rinsing process would ensure that all kernels and shells are rinsed adequately and that no batch goes unrinsed or abundantly rinsed, which would waste fresh water.

To help improve the saltwater separation process, we calculated the densities of the kernels and shell pieces and determined an optimal range for the salinity of the solution. We suggest using a saltwater solution that is closer to 32% salinity but between 32% and 36% so that the solution is between the average densities of the kernels and sinking shells. As we only have relative densities of kernels and shells, it is possible the salinity of the solution needs to be slightly higher. (See **Appendix E** for the mass of salt for the volume of water to achieve 32% to 36% salinity)

Additionally, after timing each of the tasks of each process and summing the times (shown in Table 1), we noticed an 8-hour disparity between the sum of value-added labor time and the total labor time spent on the process. This means that there are 8 hours of wasted time and transportation time--or time that does not go toward adding value to the argan oil product. There are some necessary steps in the non-value-added time, such as setups and transportation of materials, but this time disparity shows that the process has very promising potential to be optimized once it is industrialized and fully standardized.

### 5.1.2 New Saltwater Bath

The new saltwater bath increases the batch size of the process from three hundred grams of nut mixture to fifteen kilos of nut mixture. As it takes approximately five minutes to separate a batch, this increased batch size is estimated to increase the throughput of the saltwater separation by five thousand percent.

However, despite the great increase in throughput and batch size for the separation process, the greatest inefficiency is the time required to 'quality check' the separation process and manually separate pieces of shell from the kernel mixture. Based on data collected on a batch of Ketura-grown argan fruit, the kernel mixture is roughly 17% shells and 83% pure kernels. While this may seem like a good success rate of separation, this proportion of defects takes one hour per kilo of mixture to sort and remove shell pieces. Moreover, it is imperative that there are a few shells as possible when the kernels are pressed because it decreases the amount of oil that can be extracted and can get stuck in the press. When a piece of shell gets stuck in the oil press, the machine must be stopped, taken apart, and put back together in order to remove the problematic shell piece. Consequently, the cycle time of the saltwater separation is not quite as important as the effectiveness of the separation. We propose additional changes using the new saltwater bath to improve the effectiveness of the saltwater separation in section 5.4.3 below.

## 5.2 Value of the Larger Nuts

Many of the significant hold-ups in the process are related to the largest groups of nuts. The most significant variation introduced by these nuts is that they contain more than one kernel. This is important in cracking the nuts, most larger nuts need to be thrown into the cracking machine two or three times to get all the kernels out of the shell, and this is not always effective. Larger nut shells also often contain air bubbles meaning they need to be sifted out of the mixture before they can be put into the saltwater bath as they will not sink.

These process inefficiencies being so concentrated in the larger nut groups leads to the question: is it more worthwhile to sell the larger argan nuts? In the interest of creating a more efficient process that can handle more of Israel's nuts, we believe that the larger nuts should be sold unless they are the only nuts available. Solowey believes peeled larger nuts can be sold for somewhere between ten and fifteen shekels per kilo. Selling these nuts is advantageous as it is both profitable and frees up the process to help support more Israeli argan groves.

## 5.3 Process Scalability/Scenario Analysis

### 5.3.1 How Will the Process React to Changes in Initial Conditions

The sensitivity and scalability analyses in sections 3.4 and 3.5 show that the greatest impact on production is the volume of argan fruit and available labor hours (detailed scenario and scalability analyses are contained in **Appendix F** and **Appendix G**). These analyses also indicate that oil production is greatly affected by the efficiency of each step, and that increasing the efficiencies of these steps will have a compounding increase on the overall process.

If the argan oil production process cannot increase production volume in the near future, many argan orchards will disappear. Over the past several years, many Israeli argan farmers have not been able to sell their argan fruit at enough of a profit to sustain the groves, resulting in the farmers changing crops in hopes of finding a more profitable crop. Similarly, if the amount of argan fruit available in Israel decreases, Kibbutz Ketura will be greatly limited in oil production, and it will negatively affect the annual oil production volume.

### 5.3.2 What Happens as the Argan Tree Becomes More Standardized

Argan trees are still relatively new from an agriculture perspective, and the optimal tree is not yet being cloned for optimal nut production. Currently, there is high variation between different nut sizes, shapes, and number of kernels, leading to high variation in the process. As the argan tree becomes more standardized, this variation will likely decrease. Specifically, it is anticipated that standardized argan nuts will contain one kernel and be of reasonably consistent size (Solowey, N., personal communication, February 21, 2022). This will mean that the process can be simplified and made more consistent. Specifically, the pre-cracking sorting will possibly become unnecessary, and there will be fewer large nut shells in the argan mixture following the cracking.

## 5.4 Proposed Future Changes and Research

### 5.4.1 Salt Water Waste Management

As the process scales up from its current state, more saltwater will be used to separate the kernels from the shells. For each kilo of fruit separated, the process requires approximately half a liter of saltwater. Currently, the process is only producing 8,800 kilos of fruit per year, meaning 4,400 liters of saltwater per year. This is low enough to be watered down and poured down the drain. As the process scales up, however, there will be more saltwater waste that needs to be dealt with, and this waste should be dealt with in an ecologically friendly way. We suggest a future research group look into this issue and have the following suggestions as to potential solutions.

1. Use the saltwater and argan dust from the dehydrated saltwater waste as an ingredient in a cosmetic scrub.
2. Dilute salt water with freshwater used in the process and use this to water argan trees, date trees, or other trees around the kibbutz.
3. Run this water through a column to desalinate the water and separate the argan dust.
4. AlgaeTech, a company located on the kibbutz, also has a saltwater waste problem. It may be advantageous to collaborate with AlgaeTech on solving this problem.
5. Saltwater may be a useful activator to activate charcoal made out of the argan shell.

### 5.4.2 Improving Pre-Cracking Sifting

As the process continues to produce more oil, the next bottleneck will be the pre-cracking sifting. The process as it exists right now is likely not ideal sizing-wise, and the crates likely do not have ideal hole sizing. Nuts also get stuck in holes during sifting, causing the process to take longer. It is possible that the nut-cracking based on size issues is, in fact, due to the largest nuts in each batch simply being the last nuts to be cracked in each batch. The way the cracking device works is such that when there are few nuts remaining, no nuts will be cracked. This means that if, once sorted into batches, the groups of nuts were simply poured in one after the other, this efficiency problem may be mostly solved. It also takes considerable labor time to sift the nuts into various size groups. We suggest a cabinet-like mechanism employing a series of vibration plates with removable trays. Each tray should have holes such that nuts of the appropriate size will fall into the next layer. This, combined with motors to cause the tables to shake, would allow the user to pour a mixture of nuts into the topmost tray, turn the machine on, and have the nuts sorted into their appropriately sized trays. This idea is still in the prototyping phase, and we suggest a group does further research into ideal sifting trays and possible automation.

### 5.4.3 Dual Bath Salt Water Separation

Thirty percent of the process labor time is spent manually sorting out defects in the kernel and shell mixtures. Since some shell pieces are less dense than kernels, these shell pieces float with the kernels in the saltwater separation and makeup 17% of the kernel mixture. However, since we found the floating shell pieces to have an average density of 0.924 g/mL and the kernels to have an average density of 0.979 g/mL, it still seems possible to separate these floating shells from kernels using a salt water bath. As noted previously, while the kernels and small shells have an average density less than the density of water, they still sink in the fresh water bath. As noted previously this means that likely the kernels and shells absorb the fresh water, becoming more dense and sinking to the bottom. It is likely that the densities of the shells and kernels are distinct post-absorption.

To increase the effectiveness of the saltwater separation and decrease labor time, we propose a second, lower salinity saltwater bath after the original saltwater bath. The first saltwater bath should have the same salinity as proposed in section 5.1.1, about 32% salinity, to separate the currently sinking shells, while the second bath should have a much lower salinity closer in an attempt to separate out the lower density shell pieces from the kernel mixture. It is a possibility that the kernels and floating shells are too close in density for this to be a successful solution. However, we encourage further research into this solution.

# Chapter 6: Conclusions and Recommendations

Through analysis of the process, we have identified and outlined immediate and future improvements to the process and implemented immediate solutions. The process at Kibbutz Ketura can currently produce 2 liters of oil per week and needs to make significant improvements to achieve their goal of 250 liters of oil per week in five years.

The major bottleneck of the process was the saltwater separation. To remedy this, we created a larger saltwater basin designed to process a larger batch size. The time to process a batch will remain the same, at approximately five minutes, and the maximum batch size has increased from three hundred grams to fifteen kilos. For a full batch of fifteen kilos, this basin will save over four hours of labor time. As the process scales, this will create an excessive amount of Saltwater waste. We recommend research into ecologically beneficial solutions to this problem.

**Figure 20: Salt Water Basin**

The saltwater separation, however, is only about 83% effective, leading to 30% of the process labor time being spent sorting through poorly separated mixtures. For the near future, we recommend research into a second saltwater bath to be used to separate out the defects in the kernel mixture. If the process scales as it is anticipated, we recommend the purchase of an optical separator in three to five years to significantly increase the throughput of the process.

The next major process bottleneck will be the current method of sorting the nuts by size before cracking them. The current method of manually shaking crates is unscalable and also inconsistent. We suggest research into the ideal sifter's whole shape as well as the construction of an automated sifting mechanism so as to reduce labor time and increase effectiveness.

In analyzing the scalability of the process, we found that while the process is very methodical, it is not standardized. Standardization is important in any process as it decreases process variation. We have made many small changes towards process standardization, and we recommend a continued focus on standardizing process steps. This standardization will make process issues clearer such that they can be addressed and is also a necessary step towards a scalable process.

Between the changes we have made and the changes we recommend, the process can process larger quantities of nuts. We estimate the process can currently process 3,000 kilos of fruit each year and has the potential to process 10,000 kilos of fruit within three years. With added capacity at Kibbutz Ketura, the process can support both Ketura's expanding argan grove and argan farmers throughout Israel.

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# Appendices

## Appendix A

Labor Time for Process Tasks

Cycle times for a process starting with about 11 kg of dried argan fruit

| Sub Processes | Task | Time (sec) | Time (min) |
|---|---|---|---|
| Peel argan fruit | Potato peeler machine is on | 666 | 11.10 |
| | QC checks the argan fruit are peeled | 75 | 1.25 |
| | QC checks there are no fruit in peel waste | 85 | 1.42 |
| Pre-Cracking sorting | Nuts are put in sifter 1 and shaken | 60 | 1.00 |
| | Nuts are scooped into sifter 2 ** | 56 | 0.93 |
| | Sifter 2 is shaken 4 times | 22 | 0.37 |
| | All batches are passed through sifter 2 again | 16 | 0.27 |
| | Nuts are poured into sifter 3 and shaken ** | 30 | 0.50 |
| | Nut size groups are put in different trays | 90 | 1.50 |
| | ** QC check for rotten or empty nuts during scooping | 20 | 0.33 |
| Cracking the nuts | Test a few nuts and adjust cracking machine | 60 | 1.00 |
| | Pour all the nuts and machine cracks nuts | 440 | 7.33 |
| | QC checks the nuts are cracked and separates uncracked | 480 | 8.00 |

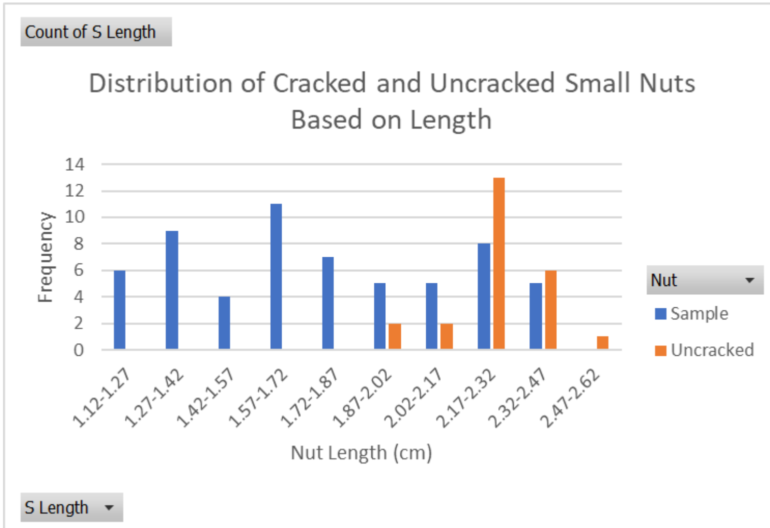
| | | | |
|---|---|---|---|
| Pre-Separation sorting | Sift out large shell bits | 69 | 1.15 |
| | QC 'sweep' sorts thru shells for uncracked and kernels | 513 | 8.55 |
| | Sift out argan dust | 141 | 2.35 |
| Separation and Rinse | Pour 3 cups | 56 | 0.93 |
| | Agitate surface | 80.5 | 1.34 |
| | Scoop kernels | 476 | 7.93 |
| | Rinse kernels | 192.5 | 3.21 |
| | QC Checks defect 1 (kernels in shells) | 241.5 | 4.03 |
| | Rinse the shells | 192.5 | 3.21 |
| | Shells are in the freshwater | 49 | 0.82 |
| | Move the kernels to freshwater | 164.5 | 2.74 |
| | Rinse the kernels | 91 | 1.52 |
| | Move kernels to drying | 94.5 | 1.58 |
| | Rinse shells | 168 | 2.80 |
| | Move shells to drying | 63 | 1.05 |
| Post separation sorting | Manually sort out the shell pieces in kernel mixture | 3600 | 60.00 |
| Drying | Kernels and Shells dry on rack | 1 day | 1 day |
| | Roast batch 1 of kernels | 1260 | 21.00 |

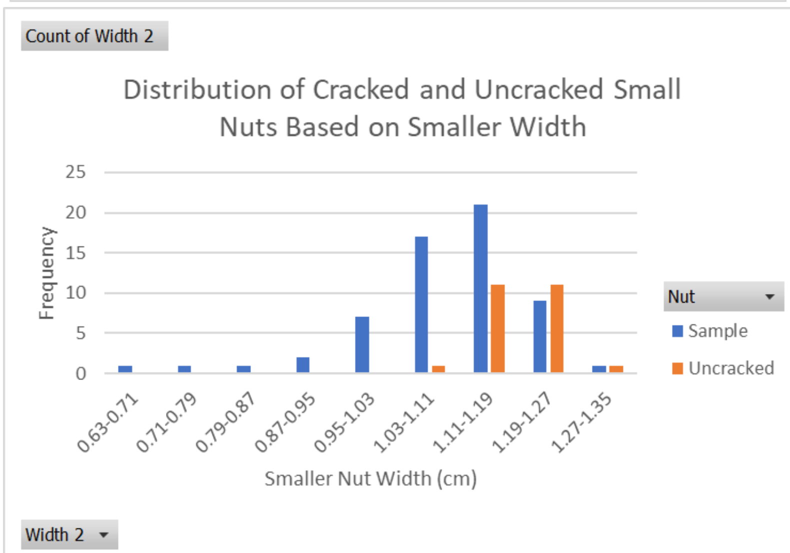
| | | | |
|---|---|---|---|
| Roasting the kernels | Set kernels aside to cool down | 75 | 1.25 |
| Pressing kernels for oil | Continuously add kernels and run press | 2400 | 40.00 |
| | End cycle running of the press | 120 | 2.00 |
| | Clean press machine | 8 minutes | 8 minutes |
| Separating pure oil | Let pressed oil and argan paste sit and separate ** | 2 weeks | 2 weeks |
| | Drain and collect 90% of the oil | 20 | 0.33 |
| | Drain and collect the last 10% | 180 | 3.00 |

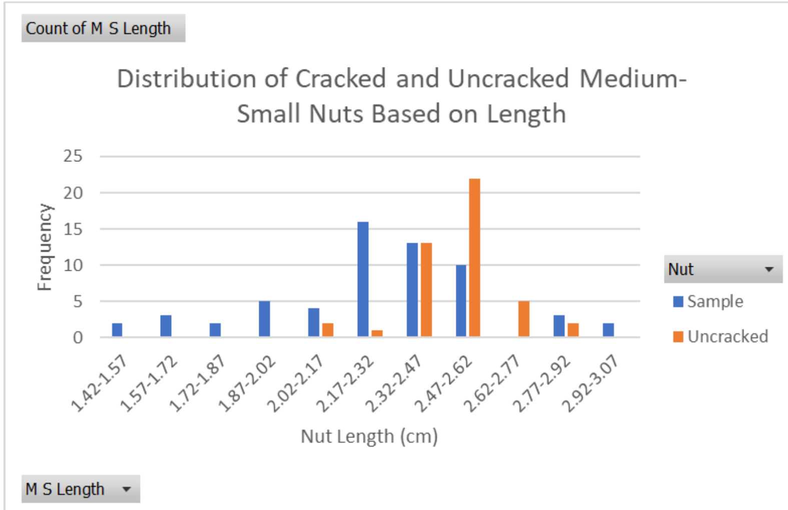
** this is not an active labor time

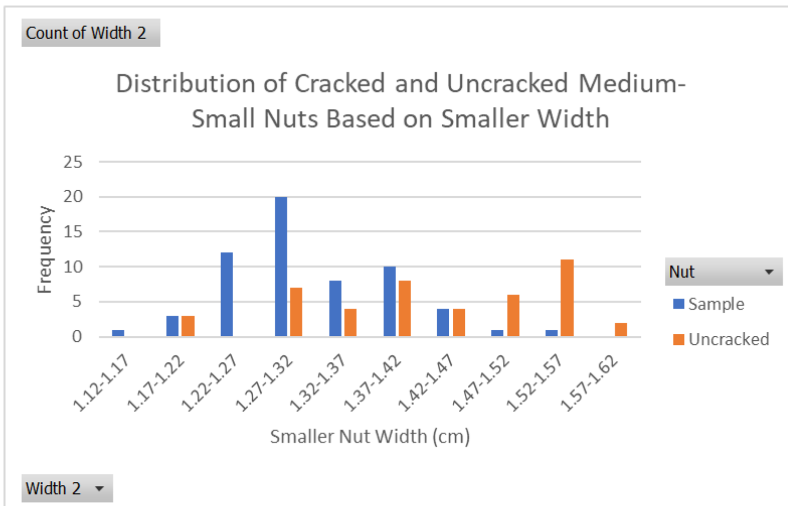
# Appendix B

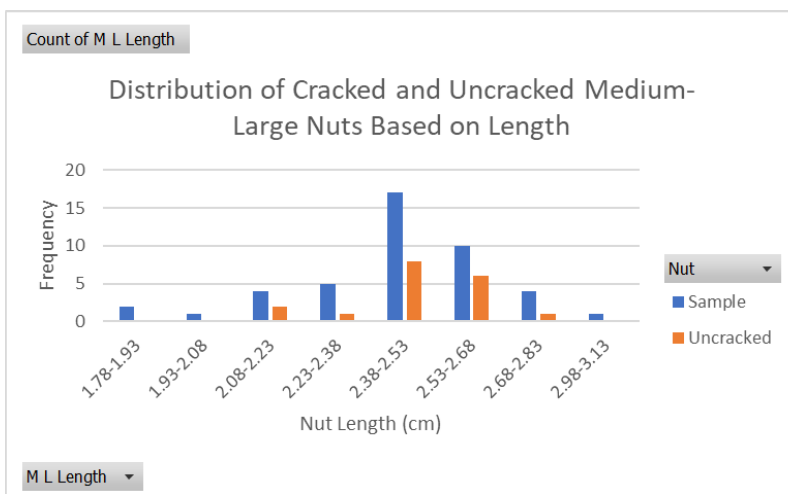
Distribution of Nut Lengths and Shorter Widths by Size Groups

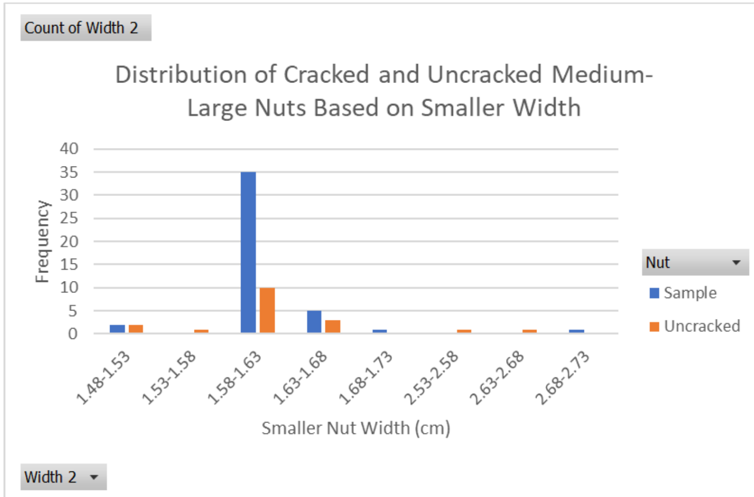


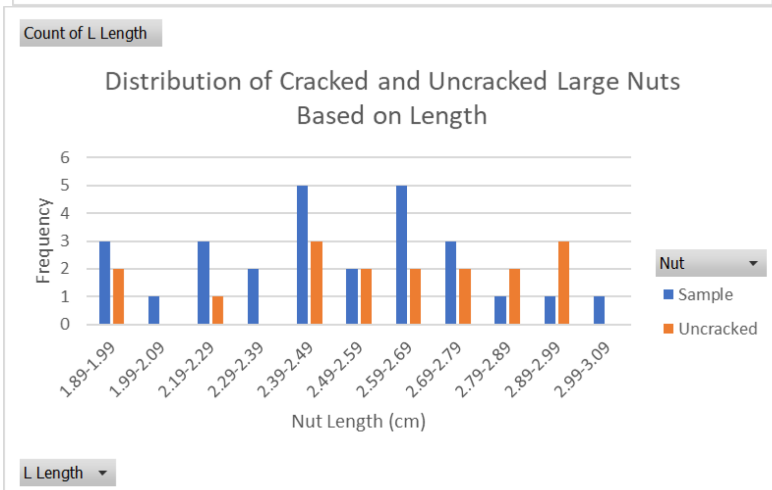

Count of M S Length
Distribution of Cracked and Uncracked Medium-Small Nuts Based on Length
Frequency
25
20
15
10
5
0
1.42-1.57
1.57-1.72
1.72-1.87
1.87-2.02
2.02-2.17
2.17-2.32
2.32-2.47
2.47-2.62
2.62-2.77
2.77-2.92
2.92-3.07
Nut Length (cm)
Nut
Sample
Uncracked
M S Length


Count of Width 2
Distribution of Cracked and Uncracked Medium-Small Nuts Based on Smaller Width
Frequency
25
20
15
10
5
0
1.12-1.17
1.17-1.22
1.22-1.27
1.27-1.32
1.32-1.37
1.37-1.42
1.42-1.47
1.47-1.52
1.52-1.57
1.57-1.62
Smaller Nut Width (cm)
Nut
Sample
Uncracked
Width 2

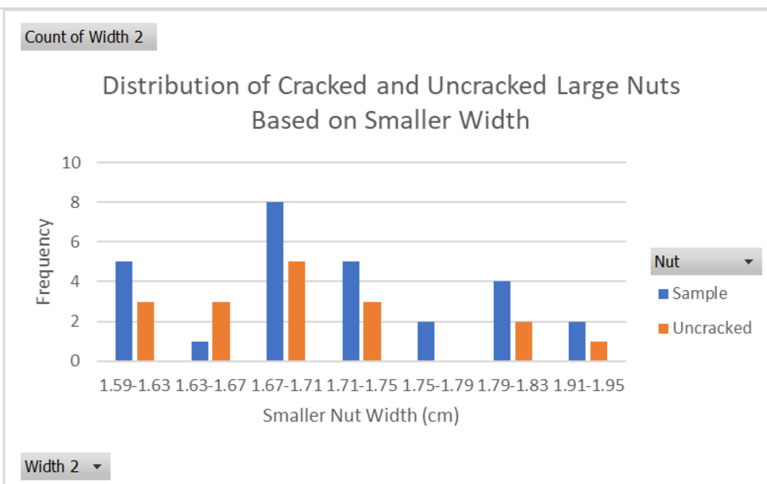

Count of M L Length
Distribution of Cracked and Uncracked Medium-Large Nuts Based on Length
Frequency
20
15
10
5
0
1.78-1.93
1.93-2.08
2.08-2.23
2.23-2.38
2.38-2.53
2.53-2.68
2.68-2.83
2.98-3.13
Nut Length (cm)
Nut
Sample
Uncracked
M L Length



Count of Width 2
Distribution of Cracked and Uncracked Medium-Large Nuts Based on Smaller Width
40
35
30
25
20
15
10
5
0
Frequency
1.48-1.53
1.53-1.58
1.58-1.63
1.63-1.68
1.68-1.73
2.53-2.58
2.63-2.68
2.68-2.73
Smaller Nut Width (cm)
Nut
Sample
Uncracked
Width 2

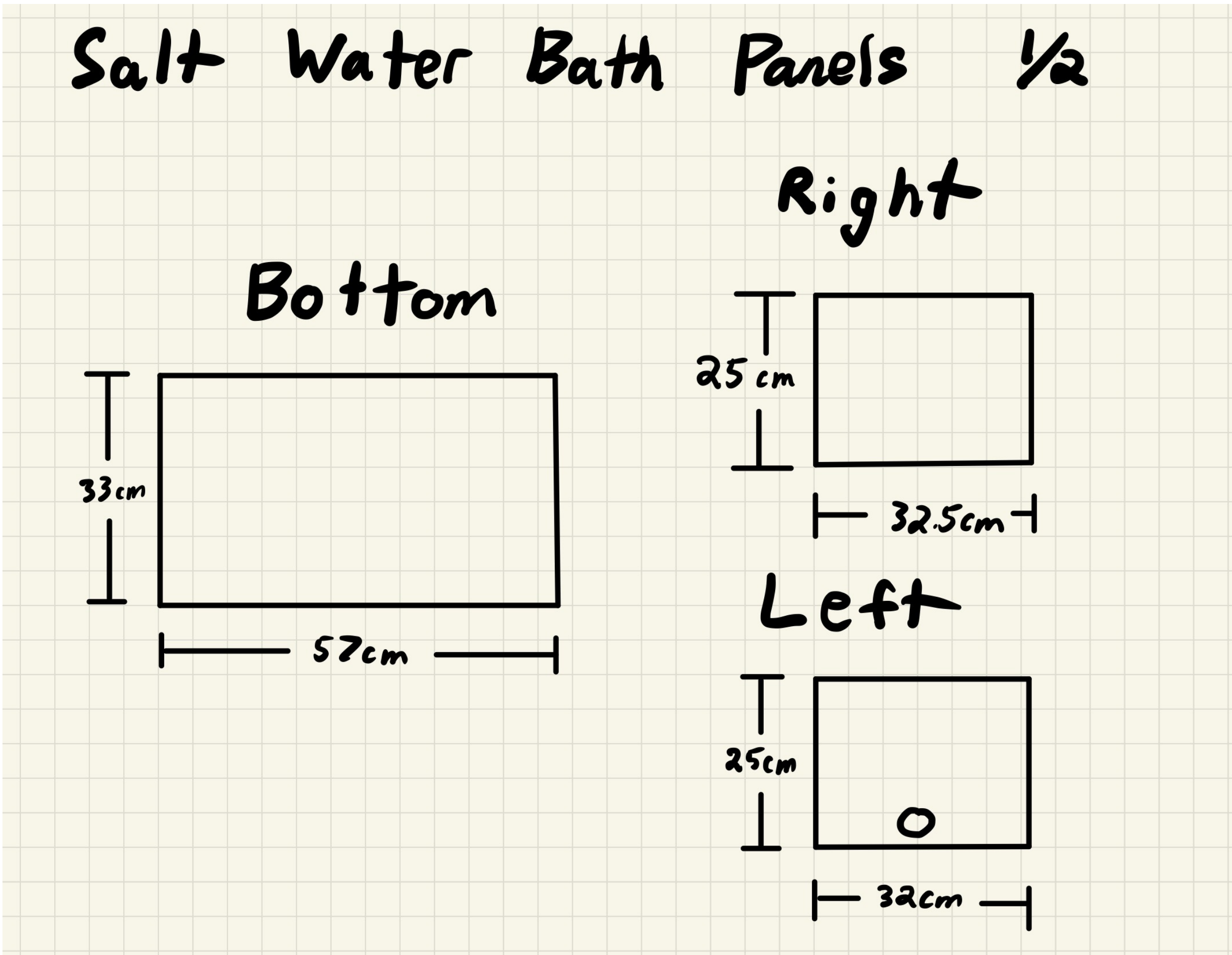
Count of L Length
Distribution of Cracked and Uncracked Large Nuts Based on Length
6
5
4
3
2
1
0
Frequency
1.89-1.99
1.99-2.09
2.19-2.29
2.29-2.39
2.39-2.49
2.49-2.59
2.59-2.69
2.69-2.79
2.79-2.89
2.89-2.99
2.99-3.09
Nut Length (cm)
Nut
Sample
Uncracked
L Length

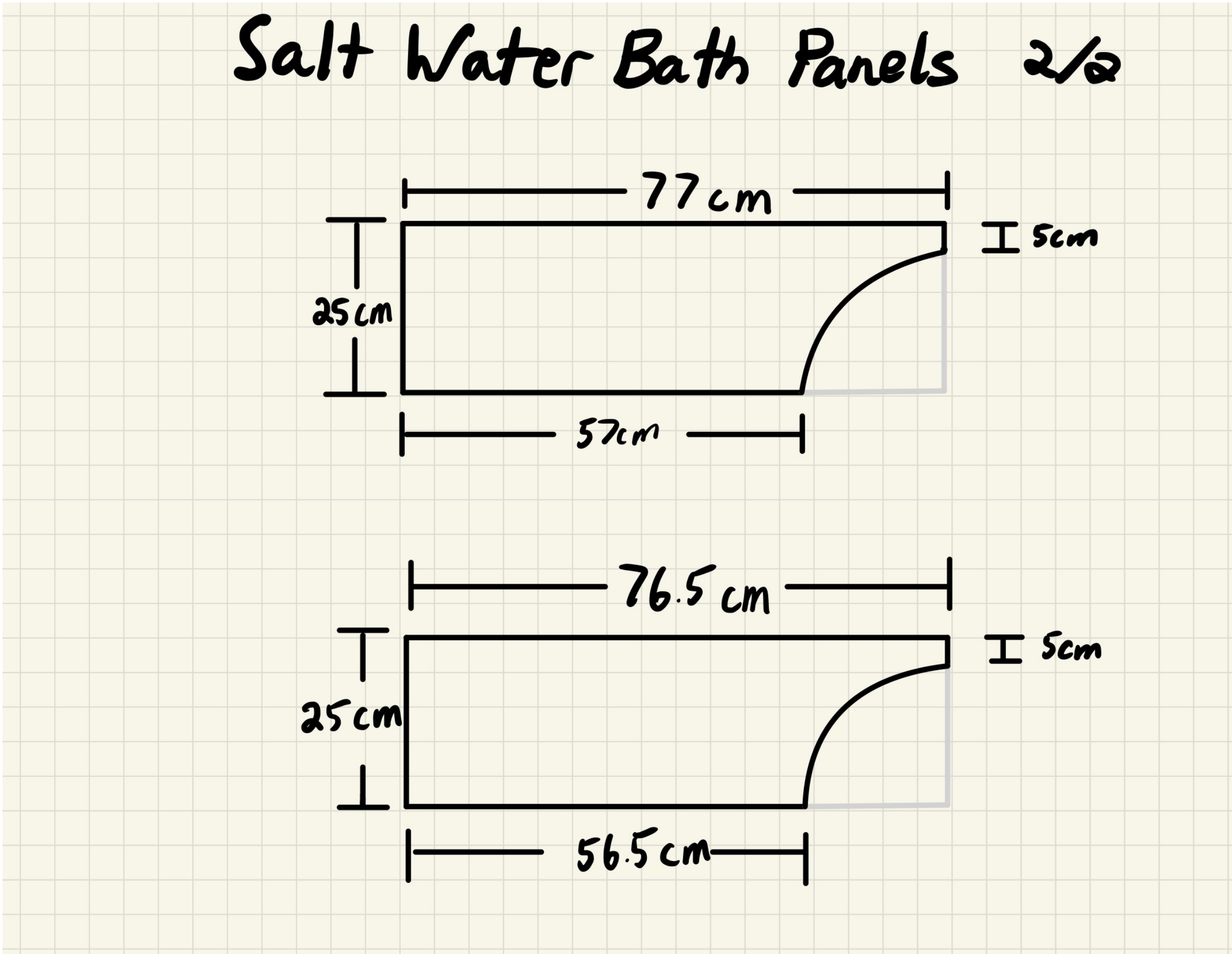



Count of Width 2
Distribution of Cracked and Uncracked Large Nuts Based on Smaller Width
10
8
6
4
2
0
Frequency
1.59-1.63
1.63-1.67
1.67-1.71
1.71-1.75
1.75-1.79
1.79-1.83
1.91-1.95
Smaller Nut Width (cm)
Nut
Sample
Uncracked
Width 2

## Appendix C

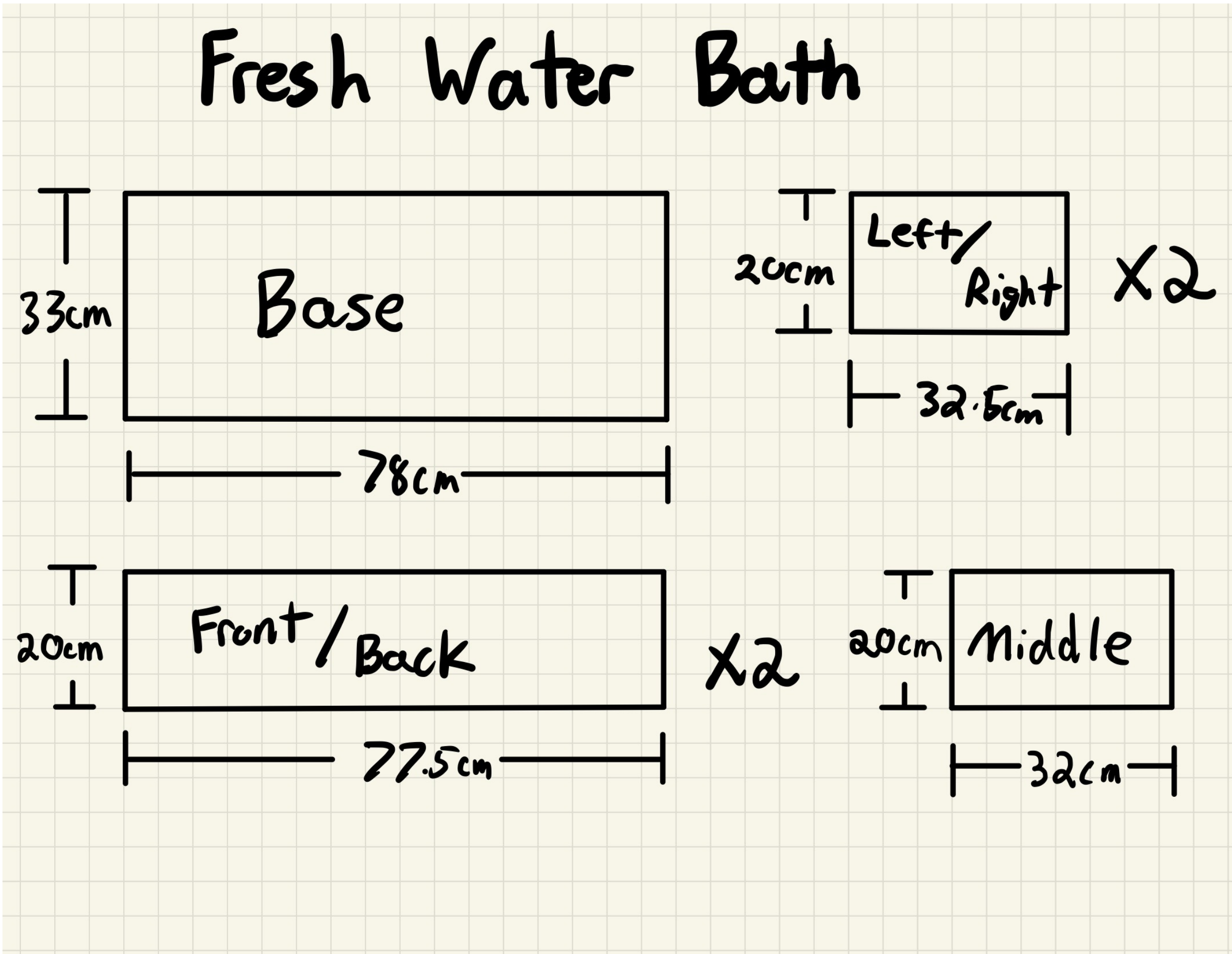
Salt Water Basin Diagrams




Salt Water Bath Panels 2/2
77cm
5cm
25cm
57cm
76.5cm
5cm
25cm
56.5cm

**Appendix D**

Fresh Water Bath Diagrams



# Appendix E

Salt Required for Volume of Water

| Water (L) | Min Salt (g) | Max Salt (g) |
|---|---|---|
| 4 | 460 | 520 |
| 5 | 575 | 650 |
| 6 | 690 | 780 |
| 7 | 805 | 910 |
| 8 | 920 | 1040 |
| 9 | 1035 | 1170 |
| 10 | 1150 | 1300 |
| 12 | 1380 | 1560 |
| 14 | 1610 | 1820 |
| 16 | 1840 | 2080 |
| 18 | 2070 | 2340 |
| 20 | 2300 | 2600 |
| 22 | 2530 | 2860 |
| 24 | 2760 | 3120 |
| 26 | 2990 | 3380 |
| 28 | 3220 | 3640 |

| | | |
|---|---|---|
| 30 | 3450 | 3900 |
| 32 | 3680 | 4160 |
| 34 | 3910 | 4420 |
| 36 | 4140 | 4680 |