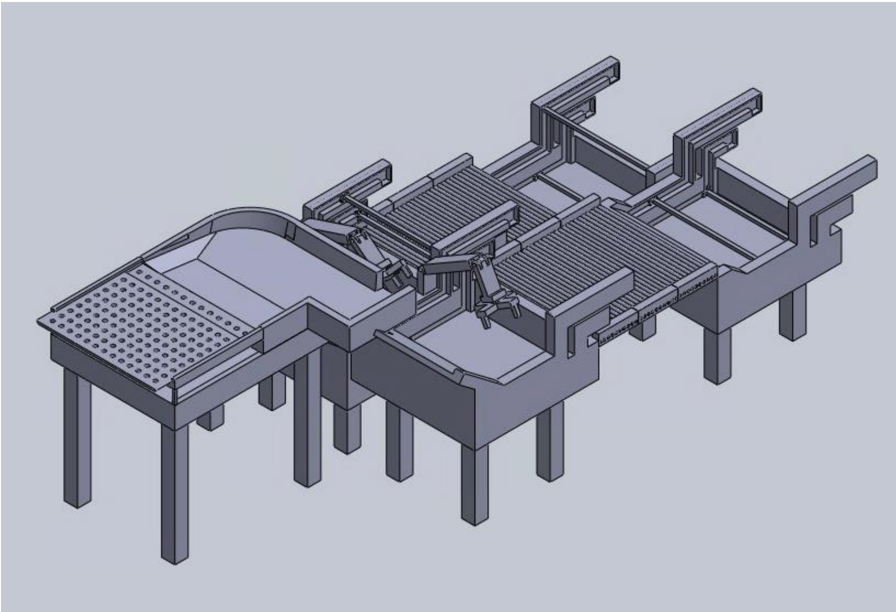
Evaluating Methods to Separate Argan Kernels and Shells



An Interactive Qualifying Project Submitted to the Faculty of
Worcester Polytechnic Institute
In partial fulfilment of the requirements for the Degree of Bachelor of Science by
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Abstract

The accelerating production of argan nuts in Kibbutz Ketura, Israel has necessitated the automation of separating argan kernels and shells that can be implemented on a large scale. We researched existing separation processes and applied the principles they employ to develop experiments to separate the kernel from the shell with friction, density, aerodynamics, and size. Using Archimedes' principle with saltwater, we developed a scalable saltwater procedure that separates kernels and nuts with a 95% effectiveness.

Acknowledgements

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Results: Density Test	Robert Kramer	All
Results: Sifting Prototype	Robert Kramer	All
Results: Aerodynamics Test	Alexandria Lehman	All
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Introduction

The future gold of the Israeli desert is not underground. It is hard as a rock, its tree needs 30 litres of water a day, and it is currently largely untapped. Argan oil, produced from argan nuts, has become a valuable export thanks to its utility in the cosmetic and cooking industries. Historically, argan oil has been primarily produced in Morocco where the *Argania spinosa* tree is native, and where the oil has seen such success it has been dubbed “the gold of Morocco” (Ananné, 2020). Recently, desert communities in Israel have become interested in argan because of its low water and maintenance requirements, as well as its considerable economic growth potential. As of 2011, over 40% of Israel's field crops and vegetables were grown in the Negev Desert, a hyper-arid region (Fedler, 2011). Correspondingly, water management in agriculture is of great importance. Date palms have been the plant of choice for many generations in Israel; however, due to its high-water requirements, some Israeli farmers have begun to diversify with argan. Furthermore, the high economic growth predicted with argan is also appealing. Economists predict the argan oil market to have a compound annual growth rate of 10.8% from 2020 to 2027 (Grand View Research, 2020). Naturally, desert farmers are becoming increasingly interested in argan because it is a crop that uses little water while promising a high return on investment. Kibbutz Ketura, a community located in the Arava Valley in Israel, is pioneering this addition of argan in the Israeli desert.

Attempts to industrialize argan oil production have been limited until recently due to the difficulty of cloning argan trees, the slow growth of the tree itself, and the remarkable hardness of the inner shell of the nut (Solowey, 2021). In order to process an argan nut, first the outer, fleshy fruit is dried and removed, then the inner shell is cracked and separated from the oily kernel. To date, the process for separating the argan kernel from its shell has been mostly conducted by hand. In Morocco, where workers are abundant and inexpensive, the manual process remains viable, but this is not the case in Israel where manual solutions are more expensive and not sustainable long term. As Kibbutz Ketura increases their production to an annual rate of 151,200 kilograms of nuts, they are eager to explore automated solutions as the manual separation technique is not scalable.

Current commercially available automated solutions are unable to separate small fragments of kernels and shells, and therefore lose valuable product. Without effective existing solutions, our project explored ways to improve the argan nut separation process for both the whole kernels and shells, and kernel and shell fragments. Our sponsor, Nadav

Solowey, requested a goal of 95% success during separation to reduce the time spent manually picking through the kernel shell mixture. This high rate of separation is essential because the quality of the oil is reduced by shell contaminants. Mr. Solowey also requested a method that would allow for the eventual production rate of 100 kilograms of nuts per hour to plan for the projected growth of the grove. To achieve this goal, we developed the following three objectives: 1) analyse the characteristics of argan nuts, 2) develop and test separation prototypes, 3) propose a separation mechanism. With these objectives, we designed a conceptual solution that can be implemented in the kibbutz's manufacturing facility. Our proposed design requires no manual operation and can be scaled to process upwards of 100 kilograms of nuts per hour.

In this report, we explore topics relating to Israel's agriculture, and the forces driving the addition of argan nuts, including the agricultural benefits of argan trees and their production process. We then describe specific research goals along with a plan to implement them. We then investigated the physical properties of the nuts and potential prototypes to establish a means of separation, which was then scaled conceptually and presented in an integration plan which will be sustainable for the next two decades.

Background

I. *Agricultural Economy of the Kibbutzim of the Negev Desert*

Dating back to the Middle Bronze Age (2000 BCE), the inhabitants of the Israeli desert have had a longstanding agricultural tradition of innovating to adapt to a difficult environment. Water scarcity has shaped the development of Israel such that it has become a powerhouse of water treatment and conservation as evidenced by the six established desalination plants and the invention of plastic drip irrigation, a water saving technique invented in the Negev (Young, 2017). Even with the strong water infrastructure, Israel has experienced issues coping with the population growth, farmed land, and settled communities (Galnoor, 1978). This has put an increasing strain on the kibbutzim in southern Israel, which have traditionally featured agriculture-based economies.

One crop of significance is the date palm as Israel is the 5th largest exporter of dates in the world (Top countries for export of dates, n.d.). However, as the climate is changing, the issues with the date palm are becoming more relevant, namely their excessive water requirement and the monocropping risk they present as they are currently implemented at Israeli kibbutzim. Date palms in Saudi Arabia, a country with a desert climate comparable to Israel's, have an average daily water requirement of 184.4 litres per day, with the tree requiring less water in the winter (97 litres per day in December) and more water in the summer (854 litres per day in June) (Bhat et al., 2012). While their roots can extract water and nutrients from up to 10 meters deep, the crop still requires a large amount of water to be provided by farmers (Carr, 2012). Furthermore, the overwhelming use of dates over every other crop has the region in a precarious position. In the unfortunate circumstance that an infectious disease appeared that affected date trees, a major income source for the community of kibbutzim could be sharply reduced. Thus, the long-term need to diversify the agricultural economy of the region is evident.

This brings us to Kibbutz Ketura, one particular kibbutz currently feeling these environmental and economic challenges. Nestled in the Negev desert, Kibbutz Ketura was formed in 1973 when the Zionist-labor movement was in its peak popularity (Judaea, 2014). Kibbutzniks have been working the land for almost 50 years. Kibbutz Ketura currently has several industries centred around land use, including a large date farm and a partnership with two companies: the Arava Power Company, which established Ketura Sun, a 20-acre solar power plant, and Algatechnologies, a company which grows microalgae. Along with these ventures, Nadav Solowey and the members of Kibbutz Ketura are interested in exploring another agricultural avenue in argan trees.

II. Argan Economy and Feasibility in Desert Environment

Kibbutz Ketura is interested in argan trees since they are well suited for a desert climate. According to Zunzunegui et al. (2018), argan trees in Southwestern Morocco receive about 34-452mm of rainwater a year in inland sites. Even in years with low rainfall, the tree does not require additional water. Argan trees require less water from farmers since they are able to rely on brackish groundwater as their main source of water (Zunzunegui et al., 2018). According to Ain-Lhout et al. (2016), the trees' roots do not go deeper than 4 meters; however, the argan tree can uptake soil water from depths of 4-8.5 meters using suction. This supports Zunzunegui's finding that argan trees' main source of water is not water provided by the farmers, but rather groundwater. Additionally, although desert groundwater is high in salinity, the argan tree is adapted to handle up to 7.5 grams per litre of NaCl (sodium chloride) (Kechebar, 2017). The area near Kibbutz Ketura has salinity levels considerably lower than the argan's maximum, making this environment suitable for the argan tree (Vengosh & Rosenthal, 1994).

Kibbutz Ketura is also interested in argan trees since they show substantial promise as an economically strong and sustainable export. Economists project the argan oil market to grow from 223.9 million USD in 2019 to 507.2 million USD in 2027 (Grand View Research, 2020). Argan oil has experienced a recent surge in popularity in cosmetic, culinary, and medical applications. The versatility of argan oil is mainly attributed to the extraction methods it undergoes; mechanical (cold press) extraction mainly deals with creating edible argan oil, while chemical solvent extraction is primarily used for cosmetic applications due to added preservatives and certain chemical properties of the oil being changed (El Abbassi, 2014). Bellahcen (2013) has shown that argan oil can be used for various medicinal purposes, such as the treatment of diabetes and the prevention of cancer, due to its antioxidant compounds.

Kibbutz Ketura established an argan tree pilot program in 1985, headed by Dr. Elaine Solowey, with approximately 67 trees (Solowey, 2001). Since then, the kibbutz has found that the trees produce approximately 40kgs of fruit per year (Solowey, 2001). The amount of argan oil produced per tree is dependent upon the number of kernels the trees can produce. One fruit can contain one to three usable kernels, which make up about 13% of the de-pulped fruit weight (Harhar, 2014). One kernel is composed of about 55% argan oil, and so the production of a litre of oil requires about 40kg of argan fruit (Nerd, 1994). For Kibbutz Ketura this translated to a production of 50L of oil per year. By 1996, the original trees received 12,000L of water per year, while newer, smaller, trees required only 3,000-6,000L of water a year. When comparing these numbers to the water requirement of the date palm (310,000L per tree per year) the argan tree is much more sustainable in this desert biome. With the success Kibbutz Ketura has experienced with argan so far, they aim to further increase the number of argan trees planted to around 3,000 trees. To maintain efficient production of nuts and the success of the project, the manufacturing process needs to be improved and a plan for growth needs to be implemented to keep up with the increasing argan nut production.

III. The Current State of Argan Processing

Currently, most argan nuts are harvested and processed in Morocco. There, argan nut processing begins with the collection of fruit by hand from under the argan tree. The fruits are sun-dried for up to 28 days before they are ready to be processed (Harhar, 2010). After the outer fruit is removed, the nuts are then brought to a processing facility to be cracked. In Morocco, the traditional cracking process involves using two rocks, one flat and one sharp, and firmly striking a single nut between the two. Once the nut cracks, the kernel must be separated from the shell pieces, which is also currently done by hand. When cracked perfectly, the worker separates a whole kernel from its respective shell pieces. In Kibbutz Ketura, they use a machine to crack the argan nuts. Nuts are sorted by size and then cracked between two large metal plates. This process is less precise than doing it by hand as some nuts are crushed into fragments that are difficult to work with.

Once cracked, a thorough separation is essential as shell pieces can decrease the oil quality or clog the oil extraction machine. The time taken to separate the pieces is increased by the current cracking techniques which are not precise enough to cleanly crack every nut, resulting in dust and kernels being broken. Since separation is mostly done by hand, separating the small kernel and shell pieces takes more time, and therefore, more manual labor. After the kernels are separated, they are ready for oil extraction. In Morocco, traditional millstone techniques are used for argan oil extraction; however, chemical solvent extraction and mechanical extraction (cold-press; the technique used at Kibbutz Ketura) processes are becoming increasingly popular to match the speed required to meet argan oil demands (El Abbassi, 2014). The mechanical press method closely mimics the original hand and millstone technique, but without the manpower and fatigue that comes with manual labor. Once the oil is extracted and filtered, it is ready for packaging and transport where it is distributed to the global market.

Approximately 100 kgs of dried fruits and 15 hours of a person's manual labor produces about 60 kgs of argan nuts to be cracked and separated. Those 60 kilograms of argan nuts are converted into about 6.5 kgs of argan kernels (Matthäus, 2010). Given that the amount of argan oil yielded per nut is around 55%, 3.57kg of argan oil is produced with 15 hours of work from one person, excluding the oil extraction time (Harhar, 2014). In total, 58 gruelling hours of one worker's manual labor is required to create about 2L of argan oil (Matthäus, 2010), with each litre selling for as much as $300 (Ash, 2020). Further investigation has shown that there is a discrepancy within these numbers as one study claims that 20-25 kgs of fruit can produce 2 kgs of kernels, and thus create 1L of argan oil (ArganFarm).

The most time-consuming and least automated step in argan manufacturing is the separation process. A review of Perry's (2020), Nerd's (1994), and Matthäus' (2010) papers discussing the current state of argan processing has demonstrated that there are few separation techniques that use advanced tools or automation that are workable on the scale that the kibbutz is growing currently. This means that manual separation is currently the main bottleneck to the growth of argan processing at small facilities (Dodson, 2020). If this process were to be automated, more argan can be processed using less manual labor, effectively creating more oil at a sharply decreased cost.

A critical problem with argan oil production on Kibbutz Ketura is that kernels and shells that come out of the cracking machine which are pulverized. This represents 10 to 15 percent of the total output of the machine. The entirety of this is lost revenue, since the only way to separate this mixture is by hand, which is not time effective for such tiny pieces. As production of argan scales, the profit the kibbutz stands to lose from these pulverized nuts will increase proportionately.

We researched commercially available separation machines advertised for argan nuts, which revealed what properties are being used to separate the nuts. Two main machines stood out: the nut separation machine from Zhengzhou Great Machinery Equipment Co. and the nut separation machine from Henan Ruiya Machinery Co.. Both machines claim a separation rate of 95%, which matches the separation rate required by Kibbutz Ketura. Additionally, both machines claim to exceed the required processing rate of 100 kg/hr. The Zhengzhou machine advertises a processing rate of 300-400 kg/hr, while the Henan Ruiya machine claims a rate of 400-500 kg/hr, processing rates that work well for Ketura.

Despite their similarities, these two machines operate in different ways. The Zhengzhou machine operates by vibrating the mixture of shells and kernels on an angled conveyor belt (Figure 1). The conveyor belt has a steady stream of low-pressure air pushed through it, which causes the lighter pieces to lift off the deck and float down the incline. The heavier pieces remain on the deck and are transported to the top of the conveyor belt where they can be deposited for further processing (Gravity Separators, n.d.). The Henan Ruiya machine operates by vibrating a plate with slits in it, which sifts the mixture (Figure 2). The smaller pieces fall through the slits, while the larger pieces remain on the plate until they vibrate to the end, with the small pieces and large pieces depending on the type of nut.

Figure 1: The Zhengzhou density sorting machine.

Figure 2: The Henan Ruiya sifting machine.

Assuming these machines operate as stated by their manufacturers, each of these machines would work for both the current and projected future argan processing needs of Ketura. However, there is no way for us to confirm the legitimacy of the claims of the companies selling these machines. Our sponsor has expressed concerns that the machines these companies are advertising are general nut processors not designed for argan. There is a tendency for companies to advertise more broadly so they will be seen by as wide a consumer base as possible. If this is the case, the particular properties of argan nuts will make these machines effectively useless for the kibbutz. Furthermore, a major drawback with both of these machines is that they cannot separate the kernel and shell fragments, which causes the kibbutz to lose valuable product. Given this, we looked at other solutions able to separate the kernel and shell fragments.

As Kibbutz Ketura increases the size of their argan grove and readies themselves for larger-scale production, they are looking towards the most efficient practices to separate argan shells and kernels. The separation process and implementation plan our team has worked to create will allow the kibbutz to be able to make this step of processing more efficient and increase productivity. For the process to be useful to Kibbutz Ketura, they requested a separation rate of 95% by weight, meaning that the process should remove 95% of the argan shells from the shell and kernel mixture. This is so that little to no manual labor is needed to pick out the last of the shells from the kernels. Additionally, keeping in mind the current argan production and the future planned production, the kibbutz is looking for the separation to occur at a rate of 100 kg/hr. Currently the kibbutz has 20 dunams of trees (approximately 900 trees) which produce 1,080L of oil per year (Solowey, 2021). The planting of an additional 50 dunams has been proposed which would result in an increase to 3,780L of oil per year. This is the equivalent of 151,200kg of nuts per year which, with an average processing rate of 100kg/hr would require the solution to be run for about 4 hours a day. Therefore, this processing rate will keep up with the amount of argan the kibbutz grows, even as the orchard expands. In what follows, we describe the methods we used to provide an effective solution for Kibbutz Ketura.

Methods

The project developed a plan to improve the argan nut separation process at Kibbutz Ketura by finding a solution with a processing rate of 100 kilograms of nuts per hour while separating 95% of the shells from the kernels. To achieve this goal, we developed the following three research objectives:

1. Analyse the physical characteristics of the argan nuts.
2. Develop and test separation prototypes.
3. Design conceptual solution.

In this chapter, we describe the methods used to gather and analyse the information collected to determine an argan nut separation process that will guide the development of the argan nut industry in Kibbutz Ketura.

I. Analyse the Physical Characteristics of Argan Nuts

Argan nuts can be separated based on several physical characteristics, such as colour, size, density, or friction behaviour. Specifically, we were interested in differences between the kernels and the shells with respect to density and friction on different surfaces. We performed predominantly qualitative tests to determine if such differences exist at a significant level. An understanding of these characteristics allowed us to understand how we could manipulate their differences to separate the shells and kernels, giving us information towards what solution will work.

We used a water displacement test to determine if there are noticeable differences between the density of kernels and shells. We placed them both in water with different salinity levels. Changing the salinity of the water changes its density, which allowed us to find a water density in between the density of the kernels and the shells. At a certain salinity level, we expected one component of the mixture, either the shells or the kernels, to float and the other component to sink. We ran these tests on both complete kernel and shell pieces as well as pulverized kernels and shells.

In order to run this test, five containers were filled with one litre of water. The amounts of tap water and saturated saltwater in each container are as follows:

Table 1: The amount of saltwater and tap water in each of the containers.

Container	Saltwater (L)	Tap Water (L)
1	1.00	0
2	0.75	0.25
3	0.50	0.50
4	0.25	0.75
5	0.00	1.00

A mixture containing 1 gram of whole kernels and 12.5 grams of shells was added to each container. The water in each container was stirred upon initial introduction of the argan mixture, again after 10 minutes, and once more after 20 minutes (without stirring, shells which would otherwise sink became trapped on top of kernels and would not separate as desired). After the mixtures settled following the third stir, the kernels and shells that collected on the surface of the water in each container were collected, dried, and weighed. The ratio of the floating kernels and of the sunken shells, versus the total mass of each added to the water bath was recorded.

We also tested whether the buoyancy differences revealed in the first test would still be observed with pulverized shells and kernels. As previously mentioned, the pulverized argan mixture is the result of mis-calibration of the current cracking machine in use at Ketura. This mixture was unusable because it is not cost-effective to separate the small pieces by hand. We tested the effectiveness of buoyancy by adding a 30 mL mixture of pulverized kernels and shells to 300 mL of a 35% saturated saltwater solution (the 35% saturation being dictated by the results of the previous experiment). After mixing three times, and allowing the mixture to settle in between mixes, the part of the mixture that remained floating was sifted off of the top and separated from what sank.

The second concern, the reusability of the saltwater solution as an effective separator, is a relevant concern for manufacturing given the scalability requirements of the separation for our sponsor. If the water can only be used a few times before the quality of the separation decreases, then the buoyancy method will not be practical for large-scale automation. In order to investigate how repeated uses affect the saltwater's separation ability, the above procedure was repeated for 5 batches of pulverized nuts using the same saltwater. The saltwater solution as well as the two products of the separation were photographed to qualitatively evaluate any decrease in separation.

We investigated the friction coefficient of both the shell and the kernel. We conducted six tests, where we placed five of each component (shells with the outside down, shells with the inside down, and kernels) on both a cardboard and plastic ramp and slowly increased the height of the ramps until three of the five components (3/5 shells or 3/5 kernels) began to slide, where we then recorded the angle with an iPhone digital level. We calculated the static friction coefficients of the inside of the shell, the outside of the shell, and the kernel for each surface by taking the cosine of each angle (Figure 3).

Friction Coefficient

$$F_{Friction} = F_{Weight} * cos(\theta)$$

$$mass * gravity \; * friction\; coefficient = \; mass * gravity * cos(\theta)$$

$$friction\; coefficient \; = \; cos(\theta)$$

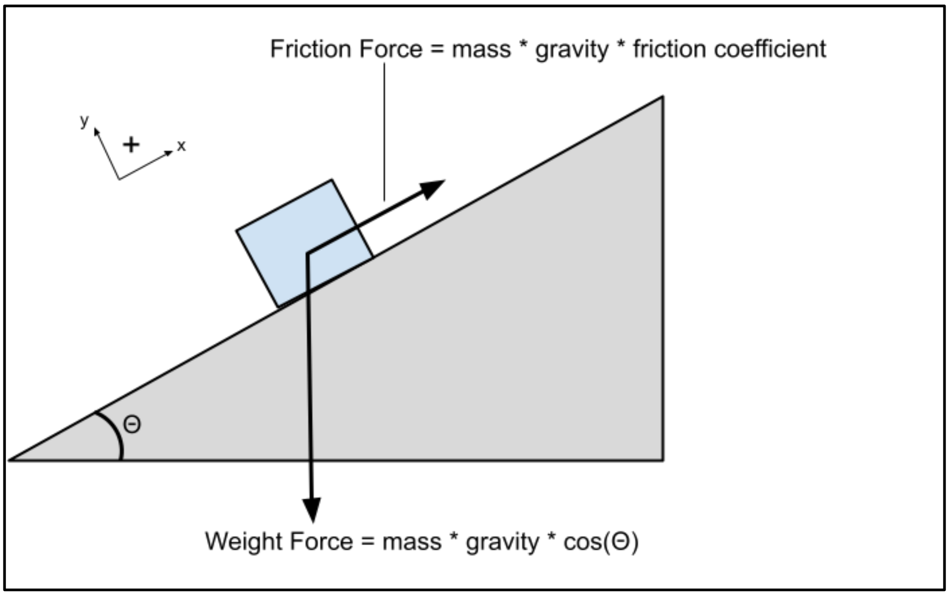

Figure 3: The cosine of the angle of the ramp is proportional to the friction force.

II. Prototypes

Inspired by the commercially available separation machines, we investigated if we could separate the kernels from the shells based on their size difference by designing a manual sifting mechanism with an adjustable slit diameter, from 1mm to 25mm. We ran trials with two different types of mixtures, one containing just the complete pieces of cracked shells and kernels, and the other a mixture of the complete pieces and pulverized pieces of shells and kernels. Each trial consisted of putting the mixture in the sifting mechanism and slowly increasing the slit size to see if most of the shells or most of the kernels were sifted out. This prototype was designed in Solidworks CAD (Computer Aided Design) software. It was 3D printed in PLA on an Ender 3 with a resolution of 0.4 mm[1].

To investigate automation based on the difference in coefficient of friction, we designed and 3D-printed a conveyor belt device with an adjustable ramp height. By adjusting the angle, the conveyor belt forms with the horizontal, we attempted to find an ideal range of angles that allowed the kernels to be carried up the ramp while the shells slid down. The ideal range was found by adjusting the angle of the ramp using a protractor in 5-degree increments, at each elevation running it to see if only kernels travelled up the belt. The angles we tested ranged from 0 degrees to 85 degrees, with a margin of error of 0.5 degrees. The ideal elevation angle we found was then used to attempt a separation of a mixture of shell and kernel pieces.

Our goal with the aerodynamics prototype was to see if blowing air at the kernel and shell mixture would successfully remove the shells from the mixture. Using a mixture of 5 whole kernels and 5 large shell pieces, this test was done by pointing a hairdryer at the mixture and running it at different speeds, angles, and distances to see if it would cause only the shells or only the kernels to move. Any difference between the aerodynamics of the kernel and shell would inform the design of a prototype to be used to achieve separation.

To achieve the first two goals, we worked with nuts shipped from Ketura to Israel and ran tests on them. Some of the issues that came about during analysis were the limitations in the tools that we had access to in our living spaces as COVID-19 restrictions prevented lab access. We were also limited by the amount of argan nuts we had available to experiment on. We were using argan nuts imported from Israel and only had access to 2.5 kilograms, meaning we needed to ration the nuts. The small quantity of nuts we were working with limited the amount of tests we were able to run and how much material we were able to separate in each test.

III. Design Conceptual Solution

We developed a conceptual design of a separation system to propose our findings to the kibbutz. This design was based on the differences in buoyancy that we had found in our qualitative tests. It was designed so that the process would be automated for maximum

[1] The same software, printer, and settings were used for the conveyor belt prototype.

efficiency. We created the design in Solidworks CAD software, including an animation to show the conceptual process.

Results

Through our research and experimentation, we identified several viable ways to separate argan nut kernels and shells. Specifically, our saltwater and sifting tests demonstrated an effective and simple separation process. These tests reveal a potential two-tiered system to separate whole argan nut kernels and kernel fragments from the shells. Sifting separates the whole from the fragmented mixture, and the saltwater bath separates the kernels and shells. In what follows, we describe the results from our friction, density, and aerodynamics tests to determine the ideal method of separation. These results are then combined in a workable separation process.

I. Friction Test

As shown in Table 2, the shells and the kernels have different coefficients of friction on both the cardboard and the plastic. During testing, the brown, outer part of the argan shells slid sooner than the white, inner part of the shells (Figure 4), meaning the outer shell has a lower coefficient of friction. Therefore, the coefficient of friction for the inner part and outer part of the shell were calculated separately. Despite this, both the outer and inner parts of the argan shells had a lower coefficient of friction than the argan kernels, indicating that friction could be used as a separation technique.

Table 2: Coefficients of friction for the kernels and shells on plastic and cardboard

	Coefficient of Friction		
	Kernel	Shell (inner)	Shell (outer)
Plastic	0.48	0.22	0.18
Cardboard	0.62	0.33	0.24

Figure 4: The outer part of the argan shell on the left, and the inner part of the argan shell on the right.

II. Conveyor Belt Prototype

To further investigate the friction coefficients, we designed a conveyor belt that runs at a variable angle and uses an anti-slip mat. We designed this in CAD software, as seen in Figure 5 below, allowing it to be 3D printed.

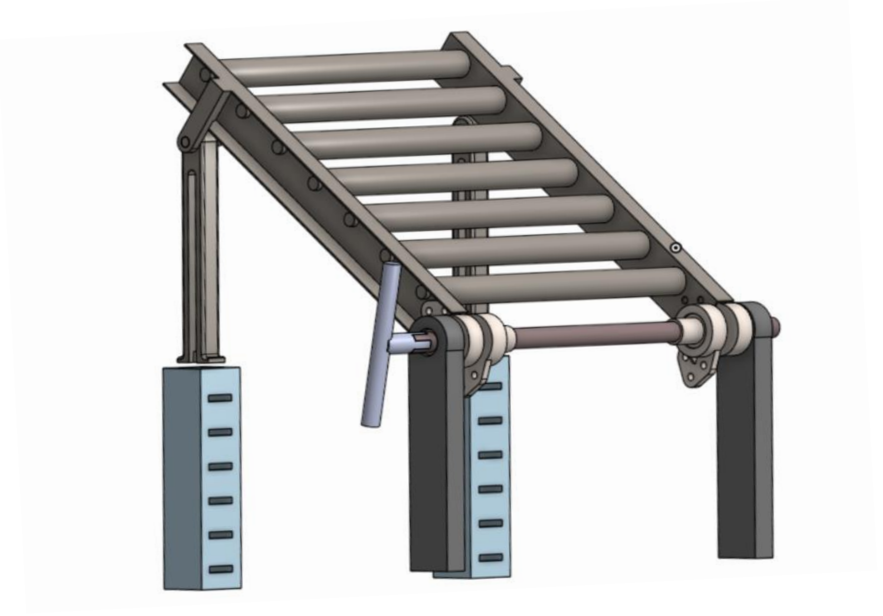

Figure 5: CAD design of the conveyor mechanism prototype without the anti-slip mat.

As seen in Table 3, at a 50-degree angle, the kernels travel up the conveyor and the shells slip down (Figure 6). However, the conveyor belt prototype was not effective at separating kernels from shells. The main issue limiting effectiveness is the fact that the majority of the mixture contains shells which resulted in the shells traveling down the belt to knock down the kernels on their way up.

Table 3: Results of various angles with conveyor belt prototype.

Angle	Kernels Rise	Shells Fall
0	Yes	No
5	Yes	No
10	Yes	No
15	Yes	No
20	Yes	No
25	Yes	No
30	Yes	No
35	Yes	No
40	Yes	No
45	Yes	No
50	**Yes**	**Yes**
55	No	Yes
60	No	Yes
65	No	Yes
70	No	Yes
75	No	Yes
80	No	Yes
85	No	Yes

Figure 6: The fully built conveyor belt.

The friction difference between the shells and the kernels may still lend itself to a separation technique we have yet to consider, but for our recommendations to the kibbutz, the conveyor belt ramp is not an effective option.

III. *Density Test*

The density tests were promising as after a few hours in regular tap water, most of the kernels floated to the top and the shells sank. The results of this initial test, performed with whole kernels and shells, are pictured in Figure 7 below.

Figure 7: The argan shells sink in regular tap water while the argan kernels mostly float.

As the data shows for a saltwater solution, kernel yield, or the number of kernels that floated on top of each mixture, is 100% for all concentrations except the full tap water solution, and 100% of the shells sank for saltwater concentrations of 50% or less (Figure 8).

In addition to kernel yield and shells separated, we report a third value, separation effectiveness. This is the product of the two percentages. Both the 25% and 50% saltwater concentrations fell into the ideal range of 100% separation effectiveness, where all the kernels floated to the surface and all shells sank. Moving forward for the rest of the buoyancy tests, a 35% saturated saltwater solution was used because it fits into the range of 25-50%.

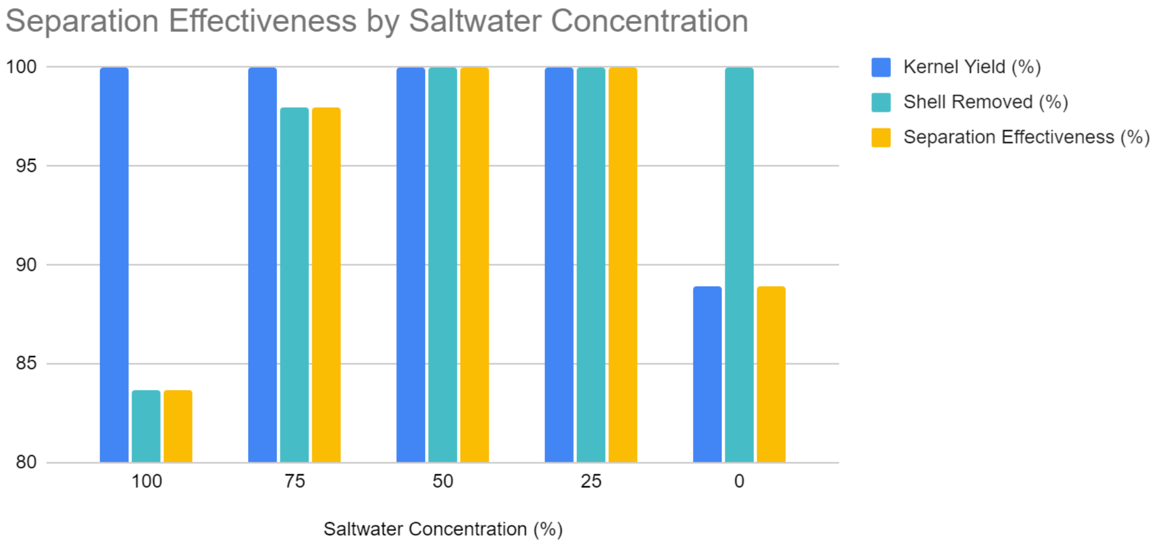

Figure 8: The results of the saltwater buoyancy test using whole kernels and shells.

The results of the buoyancy separation of the pulverized argan mixture show that the buoyancy method is less effective for pulverized shell and kernel fragments than whole pieces (Figure 9). We hypothesize that this is due to the irregularities in the material structure becoming more manifest for smaller particles sizes. Despite this, it is still notable that pulverized argan kernels, which were hitherto unusable, have been separated with an effectiveness of about 97%. This is enough separation such that the resulting kernels can still be pressed into a lower quality oil, or the remaining shell fragments can be separated by hand. Additionally, we found that the pulverized argan kernels had a higher separation effectiveness when processed separately from the whole kernels and shells.

Figure 9: The result of separation of a pulverized mixture using a 35% saltwater solution. The above bowl contains what floated, and the bottom bowl contains what sank.

We found in the saltwater reusability tests that there does not seem to be any great effect on separation after successive runs with the same saltwater used for each run (Figure 10). This is a promising sign for the scalability of this method. It indicates that the saltwater will not need to be replaced for each successive batch of argan. This test was inconclusive at determining the maximum times the saltwater could be reused. With each test, the water became more visibly polluted, never reaching a plateau (see Figure 11). Eventually we expect that there will be a limit where the water does not get any browner, and it remains to be seen if the buoyancy properties measurably change when this happens.

Figure 10: The separation results of each successive round of tests reusing water. The first test produced the leftmost two piles, the second two piles from the left, etc.

Figure 11: The progressive browning of the saltwater with each successive round of separation.

IV. *Sifting Prototype*

The sifting tests were carried out by varying the slit size of a manual sifting device. The mechanism has slits that change size, from 1mm to 25mm (Figure 12).

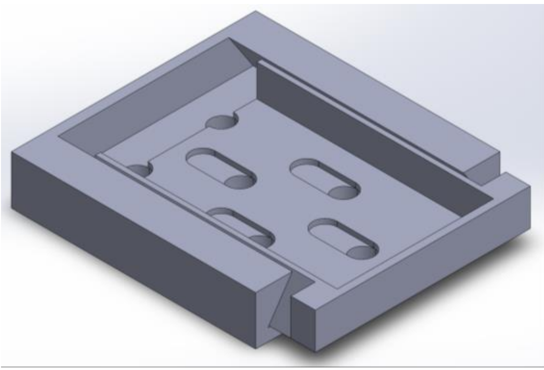

Figure 12: CAD Design of the Sifting Mechanism Prototype.

We found that a sifter is not an effective method for separating kernels from their shells, since there are too many shell fragments that are of a similar size to the kernels (see Figure 13). This was surprising as commercially available machines use this technique and report high separation rates. It can therefore be assumed that the commercially available sifting machines will not be effective for argan. Sifting based on size may remove the large shell pieces, but there will still be shell fragments that need to be picked out by hand. Despite this shortcoming, the sifter is effective at separating pulverized and non-pulverized shell and kernel pieces (Figure 13). This is relevant because the buoyancy method has proven to be more effective when whole pieces and pulverized pieces are separate. For this reason, sifting remains promising as an initial separation step, either for removing the large shell pieces or for separating whole pieces from fragments.

Figure 13: The product of separation attempts with a manual sifter. The left image is non-pulverized shells and kernels, while the right image is a mixture of non-pulverized and pulverized.

V. *Aerodynamics Test*

The observed difference in kernel and shell density and coefficients of friction lead us to believe that air current would be a viable separation technique. However, testing showed that no matter the speed or angle of the air current, the mixture of shells and kernels moved together rather than just the shells or kernels being moved. The preliminary results of the experiment made it clear that this was an avenue not worth pursuing.

VI. *Conceptual Design*

Based upon the results demonstrated by both the buoyancy tests and separation of whole and fragmented kernels via the sifting mechanism, we designed a conceptual machine based around these properties. The buoyancy tests proved that a high rate of separation is achievable by using easily scalable saltwater. As Ketura expands operations in the future, separation by buoyancy is a promising property. Additionally, it is important to note that salt and saltwater on the argan kernels can be completely washed off, having no effect on the quality of the oil, making separation by density a valid solution.

The sifting mechanism allows Ketura to separate out the whole kernels and shells from the fragmented kernels and shells. This is a beneficial feature because even if the methods employed by buoyancy are 95% effective, the resultant batch still needs to be manually checked for remaining shell pieces. This is easier for batches of entirely whole kernels and shells than for the fragmented pieces which are smaller and harder to identify. By separating these two by size, the time to process a batch of whole kernels is reduced, allowing more to be processed, and for the batch of fragmented kernels to be set aside for later processing.

To demonstrate the application of these separation principles, we developed a conceptual separation design for Ketura. We suggested that the kibbutz utilize a large-scale sifting machine to separate between the whole and fragmented kernels and shells. Following this, we proposed that the kibbutz implement two saltwater baths, one for the whole pieces and one for the smaller fragments. This water bath separation technique results in a separation success rate of 95-97% with a process that can be completely automated and be scaled to suit the needs of the kibbutz.

The amount of water necessary, and size of the tub, for any given argan processing rate is contingent upon the quantity of nuts being processed. The following recommendations are in accordance with the current kernel output at Kibbutz Ketura.

Water Bath Surface Area

$$0.6096m * 0.6096m = 0.3716m^2$$

Assuming there is one layer of kernels floating on the surface, the following calculation is performed to determine how many nuts can rest atop the water bath. The kernels are approximated to be discs with a diameter of 1 cm.

Water Bath Nut Capacity

$$0.3716m^2/(0.005m^2 * \pi) = 4{,}731\ nuts$$

The average weight of one argan nut and kernel was found to be 3.25g and 0.25g respectively. These values were multiplied by the maximum nut capacity of the bath to determine the approximate total mass of argan nuts that can be processed.

Kilograms of Nuts and Kernels/Bath

$$4{,}731\ nuts * 3.25g = 15{,}376g\ nuts$$

$$4{,}731\ nuts * 0.25g = 1{,}182g\ kernels$$

Based on our experimentation, each water cycle requires approximately ten minutes for full separation, meaning that approximately 92,256 grams of nuts (7,092 grams of kernels) can be processed in an hour. Operating under the assumption that 40 kilograms of fruit (2.59 kilograms of kernel with 55% of the kernel weight contributing to oil production) generates 1 litre of argan oil, this bath design would be able to process enough kernels for 4.9 litres of oil in an hour.

Grams of Nuts/Litre

$$\frac{7.092kg/hour}{2.59kg/L * 0.55} = 4.934L/hour$$

The tub requires 56.6 litres of water; however, testing revealed that the water can be reused at least 5 times without a significant difference in separation effectiveness. The amount of salt needed for this bath was determined to be approximately 35% saturation (total saturation: 0.36 kilograms of salt per litre of water), meaning the kibbutz requires 7.14 kilograms of salt for this level of separation.

Volume of Tub

$$(609.6mm * 609.6mm * 152.4mm)/(1,000,000) = 56.63L$$

Mass of Salt

$$56.63L * (0.36kg\ NaCl/L * 0.35) = 7.14kg\ NaCl$$

As the kibbutz increases their argan production rate the size of this tub will also need to increase. Since they plan to process approximately 10kg/hr by the end of 2024, the size of the tub will need to increase to 0.9 x 0.9 x 0.2m, requiring 123.4L of water resulting in 10.9L/hr. For a processing rate of 15kg/hour the tub size would increase to 1.3 x 1.3 x 0.2m, requiring 257.6L of water and producing 22.7L/hr. To obtain the initial goal of 100kg/hr a tub with dimensions of 4 x 4 x 0.2m is necessary. This would require 2,438.4L of water and would produce 35.8L/hr.

To automate this solution as much as possible, we developed a prototype that uses a conveyor belt to deliver the cracked nuts into a water bath. Before the shells are deposited into the water bath, they will be separated based on size as we found that there is a higher rate of separation when pieces of the same size are processed together, rather than a mixture of both large and small pieces (Figure 14).

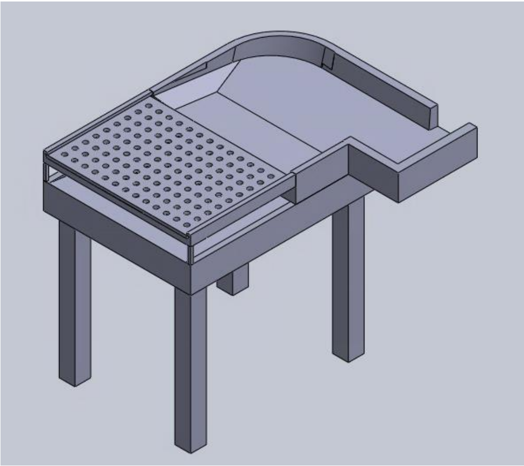

Figure 14: The sifting mechanism separates the larger kernels from the crushed ones, sending them to two separate baths. The larger pieces follow the top channel going to the right and the smaller pieces fall through, continuing on a linear path.

The water bath has a mixing arm to disturb the kernel and shell mixture, encouraging the density separation process. The mixing will occur once the shell and kernel mixture is deposited into the bath and again within the 10 minutes the batch is soaking[2]. Once the shells have fallen to the bottom of the tub, two rails, which are connected by a net and travel from one end of the bath to the other, will collect the kernels sitting on top of the water and dump them onto a conveyor belt to be rinsed and deposited into an external container (see Figure 15). The rails will be set to collect the separated kernels every 10 minutes before returning to their home position.

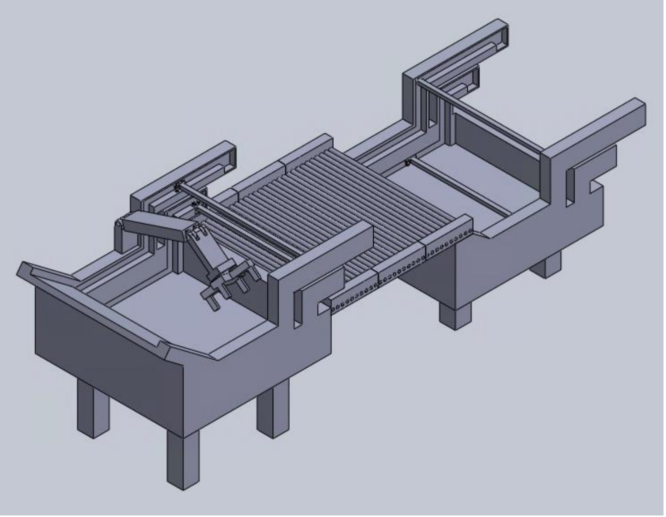

Figure 15: This assembly has a tub size of 0.6x0.6x0.2m, can process 7,092g kernels/hour (4.9L/hour) and requires 113.3L of water (56.6L/bath).

The external container mirrors the design of the initial water bath but will contain fresh water to clean the kernels before oil extraction. The collected nuts can be taken out of the bath using the rail system and checked for complete separation. The process for the separation of the large and small pieces remains the same, happening in tandem next to each other (Figure 16). In order to remove the shells that fall to the bottom of the tub, a large sieve should be placed at the bottom and emptied as needed.

[2] The ideal timing of this second mixing has not been identified. This is something that needs to be investigated further.

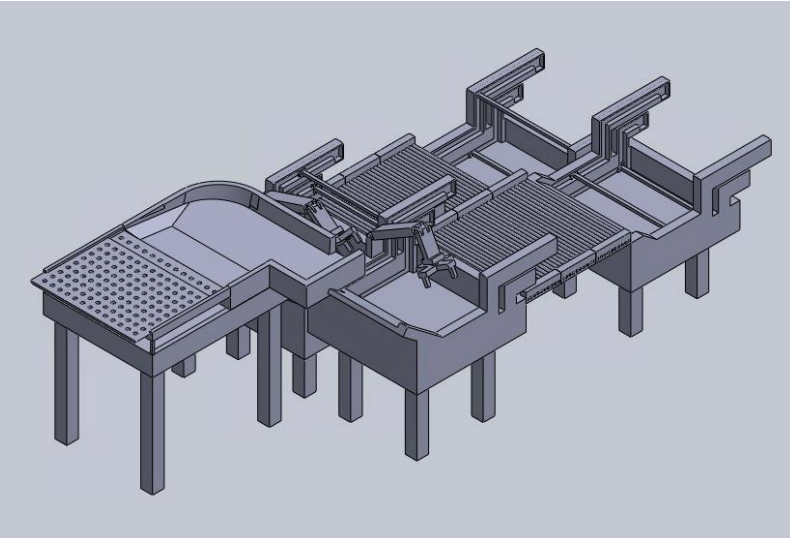

Figure 16: This figure shows the initial bath with the sifting mechanism that can separate the kernels and shells into two batches. The larger kernels and shells will go to the baths on the right, following the same procedure as that of the fragmented kernels and shells.

Conclusion

As our findings demonstrate, we were successful in achieving our goal of developing a scalable solution that has a separation effectiveness above 95%. We recommend that Kibbutz Ketura further investigate our findings to confirm the effectiveness of sifting the shell and kernel mixture to separate the whole pieces from the pulverized pieces, then putting each respective component into its own saltwater bath to separate the kernels from the shells. The scalability of this process is limited by the amount of water the kibbutz has access to as well as their ability to acquire the specific parts that would be necessary to automate the sifting, mixing, and filtration process.

We recommend further research on the application of a friction coefficient separation mechanism, the reusability of the saltwater solution, and determining the optimal nut to water ratio. These recommendations encourage Ketura to look into other techniques to determine how to make our recommendation the most water efficient.

While commercially available argan separation machines exist, the majority of these employ sifting methods which have been observed as unusable for argan nuts. Our results from the sifting tests show that our sponsor's suspicion of manufacturers providing misinformation in their advertising is correct. The kibbutz should be skeptical of machines that claim to separate agan, along with other nuts, as argan is clearly different from other nuts.

Beyond the success we have seen with saltwater on non-pulverized kernels and shells, the solution also succeeds in separating the pulverized pieces, saving the kibbutz the 15% profit which, until now, was lost. The argan nut characteristic tests we completed and prototypes we constructed reveal that sifting and saltwater baths are two effective, scalable, separation tools that can be combined to automate a separation process with an effectiveness above 95%.

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