Achieving Clarity: Separating Sediments from Argan Oil

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By

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Abstract

The objective of our project was to develop a faster and more efficient method for separating argan oil. Our sponsor expressed the need to accelerate the current gravitational process, which takes up to three weeks. Through experimentation, we found that a centrifuge was an effective approach and reduced the separation time to one hour. These findings have significant implications for our sponsor, offering a more efficient method for production and the potential to change how argan oil is processed.

Acknowledgments

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Chapter 1: Introduction

Argania spinosa is a tree species native to southwest Morocco, and its primary product is its oil. The oil has many cosmetic and health benefits, which have caused an increase in demand in recent years (Global Argan Market Size & Share Report, n.d.). The Berber community in Morocco produces most argan oil globally (Gharby, 2022). Recently, oil production has expanded outside of Morocco and now has reached Israel.

Through extensive research on desert plants, Israel has transformed deserts into productive agricultural farms. This has resulted in the growth of new plants like *Argania spinosa* in regions such as the Negev. Within the Negev, Argania has made its way to Kibbutz Ketura, where argan oil is processed and sold. Due to a different production method, oil production at Ketura requires less manual labor than in the Berber community. Despite the difference, it still takes an extended amount of time to obtain pure argan oil because of the separation process. This process consists of gravity settling solid sediments out of suspension. It can take weeks for complete separation to occur.

This project presents an opportunity to accelerate this procedure and fulfill the needs to modernize how oil can be processed, not only at the kibbutz but throughout the argan industry. From identifying promising alternative solutions, the goal for this project is:

To accelerate the rate of argan oil separation so that increased production of pure argan oil can be achieved.

To achieve this goal, our group had the following objectives: 1) Understand gravitational settlement; 2) Understand the centrifugation process; 3) Provide guidance for the future of the argan in Ketura and Israel based on our investigations.

Chapter 2: Background

2.1 The Argan Tree and its Fruit

The Argan tree, *Argania spinosa*, is native to southwest Morocco where it grows in a harsh and arid environment (Morton & Voss, 1987). It can withstand temperatures up to fifty degrees centigrade and has adapted to the desert environment (Ellerbeck, 2022). Due to these dry conditions, argan trees consume little water, requiring at most eighty liters per day, much less when compared to other commercial trees grown in the desert (N. Solowey, Personal communication, November 16, 2022) (Amhal, 2021).

Figure 1: Stages of the argan, from the fruit to the nut to the kernel. This figure demonstrates the different stages of the argan fruit during the process and how it looks.

The primary product of the argan trees is its fruit, which is ovular in shape with a diameter ranging from one to four centimeters. The argan fruit, nut, and kernel are shown in Figure 1 above. The fruit has a tough outer peel that protects the nut inside. This nut contains the argan kernel, which is about the size of a sliced almond and is the source of oil. Dry conditions allow for flexibility in harvesting the fruit and processing the nuts without harming the quality of the oil (N. Solowey, Personal communication, January 18, 2023).

2.2 Uses of Argan Oil

Argan oil comes in edible and cosmetic forms, and within the past decade, research has found many health benefits. Argan oil contains high levels of antioxidant vitamin E and moisturizing compounds for hair and skin (Khallouki et al., 2005). These desirable properties have increased consumer and commercial demand for argan oil, yet the supply has remained low (L'Oreal SA, n.d.).

The cosmetic form of argan oil is scentless with a light-yellow color. The kibbutz sells this oil in a pure form or as a main ingredient in different creams. Due to the previously mentioned benefits, many cosmetic companies are interested in putting this oil into their products, such as face masks, balms, and shampoo (Goik et al., 2019). The Moroccan government has found that many companies have diluted their argan products with other oils in order to meet this demand (Institute, 2020). At Ketura, argan cosmetics range from 40 to 120 NIS (11 to 34 USD), depending on the amount of argan content and the product type.

The edible form of argan oil appears and tastes similar to sesame oil, with a more golden-brown color. These attributes result from roasting the kernels before pressing, giving a distinct flavor and scent. The edible form of argan oil is used in traditional Moroccan salads and dishes, such as amlou.

The edible form also has several health benefits. In the early 2000s, a study conducted in Morocco observed the differences between consumers and non-consumers of argan oil. The test aimed to measure the different antioxidant and cholesterol levels between groups. The consumer group had lower cholesterol levels and higher antioxidant levels, which ultimately can help prevent cardiovascular diseases such as atherosclerosis (Drissi, 2004). Another study done on prostatic cells showed that in-vitro fatty acids in argan oil have properties that have an inhibitory effect on hormone-dependent and independent prostate cancer cell lines. Although these are preliminary results, it is an advancement in cancer prevention research (El Monfalouti et al., 2010).

2.3 The Argan Oil Market

The argan oil industry is a competitive global market, with an estimated value of 300 million USD in 2022 and projected to grow at a compound annual growth rate of 11% over the next decade. By 2030, predictions estimate the market will value at around 712 million USD (Grand View Research, n.d.)(Market Research Future, 2022). This expected growth results from the high demand for a diverse range of argan products, including those used in culinary, medical, and personal care applications. Major companies, such as L'Oreal, have emerged as leading suppliers of argan products, supplying the rising demand for makeup, skincare, and other personal care items targeted at men and women (Grand View Research, n.d.).

However, the cost of producing high-quality argan products remains a challenge. The Berber method of extracting argan oil is a labor-intensive and time-consuming process, with much of the work done by hand. As a result, the manual process and the time required for oil separation contribute to the high cost of the oil. Some manufacturers attempt to meet the demand for argan oil by diluting the pure oil with cheaper oils, further impacting the quality and cost of the final product. (Grand View Research, n.d.).

2.4 Traditional Argan Agriculture: Berbers in Morocco

The Berber community in southern Morocco has tended to the endangered argan forest for generations. Their way of life and the local economy is closely tied to the production of argan oil (Aamari, 2022). The traditional method, used by the Berber women, produces pure organic argan oil with many benefits mentioned previously. The argan tree is a crucial resource for the Berber community, and losing it could have severe consequences for their culture and livelihoods. As argan oil becomes more widely recognized, companies worldwide want to incorporate it into their products. Currently, Morocco is the world's leading producer and exporter of argan oil, but other countries, such as Israel, have also recognized the potential of argan production and are investing in argan forests.

However, due to different costs regarding workers in Israel, argan farmers cannot replicate the traditional methods used by the Berber communities (Adler, 2011). Although Israeli farmers wish to enter the market, they do not want to interfere with the Berber community's lifestyle or traditions.

2.5 Argan in Israel

While many thought growing the argan trees outside of Morocco was impossible, in the 1980's Dr. Elaine Solowey traveled to different parts of the world, including Morocco, to collect all kinds of seeds. When she planted these seeds, the argan tree was one of the seeds that sprouted and grew successfully.

Since then, Israel has grown over 2,500 trees in the Ashkelon, Arava, and Negev regions. A location with recent success is Netiv HaGdud, where the Argan company Sivan grows trees in order to produce oil for its argan products. Sivan researchers created a new strain of the argan tree called Argan 100 that produces ten times the yield of nuts compared to traditional trees. (*Rare Moroccan Argan Oil*, 2012). The strain has the additional benefit of having resilience to soil disease (nocamels, 2012).

Another place that researches the properties of argan is Kibbutz Ketura. Research there includes collecting fruit from various trees, determining the oil content in the kernels, and analyzing the resulting data. Through these tests, they identify the trees that yield the highest amount of oil, which can inform their efforts to breed trees or conduct additional experiments.

2.6 Kibbutz Ketura

2.6.1 What is Kibbutz Ketura?

Kibbutz Ketura is located in the southern Arava Desert in southern Israel. Ketura is based on communal living where land, resources, and wealth are shared equally by the community members. Kibbutz members work and contribute according to their abilities while receiving what they need from the community. This way of life is different from typical Israeli life where people are more independent and only receive benefits from their employers.

2.6.2 Ketura’s Climate

The kibbutz is located in a hyper-arid desert that received about 27 millimeters of rain in 2022 (STATE of ISRAEL, 2023). Temperatures can reach up to 55 centigrade in the summer, and in the absence of a sustainable water source, traditional agriculture can be difficult. Ketura overcomes these challenges by experimenting with different farming methods and a variety of plants. In addition, the salinity of both the water source and soil in this region is very high. (Solowey, 1980).

2.6.3 Ketura’s Economy

A majority of Kibbutz Ketura’s income comes from tourism and date products. Kibbutz Ketura brings many visitors annually to its attractions, such as Israel's first solar panel field, date trees germinating from 2000-year-old seeds found in Masada, their communal values, reformed Jewish culture, and beautiful natural features nearby (Kibbutz Ketura, n.d.). In 2022, tourism sales surpassed their date sales and made a majority of the profit for the kibbutz. The sales of argan products contribute to the kibbutz's tourism profit, not the argan oil production operation. At the kibbutz, pure argan oil is sold for 2,700 shekels, or about 800 USD, per liter at the tourism center. An example of argan oil’s popularity is when more than 10,000 NIS (2,750 USD) worth of argan products were purchased in a single day in 2022. (N. Solowey, Personal communication, February 14, 2023).

Despite this, Kibbutz Ketura's members experience little direct impact from argan oil production. Members see the importance of argan oil during the celebrations of Tu Bishvat and Chanukah, which are Jewish holidays celebrated among the community. One significant challenge for our sponsor is the limited understanding of the investment potential of argan oil. Some kibbutz members may feel hesitant to invest in this emerging industry due to the well-established profitability of traditional tourism.

2.7 Steps towards Oil Extraction at Ketura

Making argan oil is a strenuous, resource-intensive, and time-consuming process, detailed in Figure 2. The procedure used at Kibbutz Ketura includes peeling, washing, sorting, shell cracking, kernel separation, additional sorting, oil pressing, and gravitational oil settling. Some of the products obtained through this process are the fruit peels and nut shells that the kibbutz uses for different environmental purposes, such as fertilizer. It takes around fifty kilograms of argan fruit to create one liter of argan oil (N. Solowey, Personal communication, January 18, 2023). Furthermore, the process requires about five days of manual work and three weeks of waiting for the oil to separate. After traditional gravitational settling, a layer of argan oil rises on top of a layer of solid kernel paste, also known as cake, solids, or sediment. After separating, pure argan oil has a shelf life of around four to five years.

Figure 2: The argan oil-making process at Kibbutz Ketura. This figure demonstrates the stages of argan oil production that lead to oil separation. The roasting for the edible oil stage is optional.

2.8 Oil Separation

Gravitational separation occurs naturally in oils, even if there is no intention to separate sediment. The gravitational method is the current method of oil separation in use at Kibbutz Ketura. After pressing, the oil is poured into a glass jar, where it begins to settle. After around three weeks, the oil is transparent and decanted, leaving a layer of solids on the bottom of the jar.

Due to the time-consuming nature of the gravitational method, we researched different solutions, such as a centrifuge, vacuum filtration, and ultrasonication, to accelerate the process while ensuring consistent oil quality. Centrifugation was chosen as it best fit our sponsor's needs and future plans.

Centrifuges use centrifugal force, which is similar to an increased gravitational force, to isolate suspended particles from their surrounding medium. The centrifugal force depends on the rotational speed and radius of the rotor. The faster the velocity and the smaller the radius, the larger the centrifugal force and the quicker solids will fall out of suspension.

Centrifuges have been used in the production of biological products to separate dirt or sediments from different types of oil (Majekodunmi, 2015). Additionally, centrifuges are commonly used in the global production of virgin olive oil to separate impurities and obtain high-quality oil (Di Giovacchino et al., 2002). Interestingly, argan and olive oil share similar physical properties and chemical composition (Cherki et al., 2006). Given this similarity, we propose that centrifugation could be a promising method for separating argan oil.

Chapter 3: Methods

The current gravitational method in use at Kibbutz Ketura is slow and inefficient. Our sponsor has already considered different separation methods including centrifugation, filtration, and pressing. Centrifugation was hypothesized to be the best replacement for the current procedure due to its repeatability and effectiveness in similar use cases (Di Giovacchino et al., 2002). For comparison purposes, the rate of gravitational settling was quantified and recorded. We needed a test to measure the rate that the oil became clear for both methods. To achieve this objective, we created an optical test that measures clarity in the sample. The clarity test is a consistent measurement for each method in order to keep results directly comparable. We used the same 50 mL test vial for all experiments. With a constant volume and shape, the standardized container removed variability between the different tests by keeping the volume of the liquid consistent. Figure 3 shows the vials used throughout the different experiments.

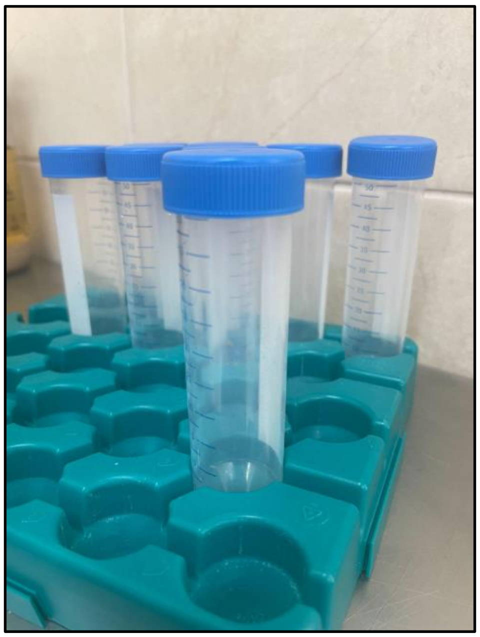

Figure 3: 50 mL test tube vials used for the optical test, gravity separation, and centrifugal separation.

3.1 Gravitational Settling

We tested the gravitational settling separation method as a function of separation and time by recording the volume of separated liquid and solid in the test tube.

Figure 4: Gravitational settling method in progress. 45mL of oil was used to find the gravitational separation rate for 14 days. The yellow liquid is cloudy oil and the white paste at the bottom is the separated sediment.

To obtain data, we measured the volumes, in milliliters, of the sediment collected at the bottom and the oil that rose to the top. Measurements were recorded for 14 days from a 45 mL sample of unsettled solution. The gravity settling process is seen in Figure 4 above. We calculated the settling rate from the data collected from the trial.

3.2 Measuring Oil Clarity Over Time

To determine the clarity of the oil, we created an optical test using different shades of black, as seen in Figure 5. To test samples, we checked if the number below the circle was visible when looking through the vial of oil. The clarity of the oil was put into a spreadsheet and plotted over time, representing the rate of change of clarity.

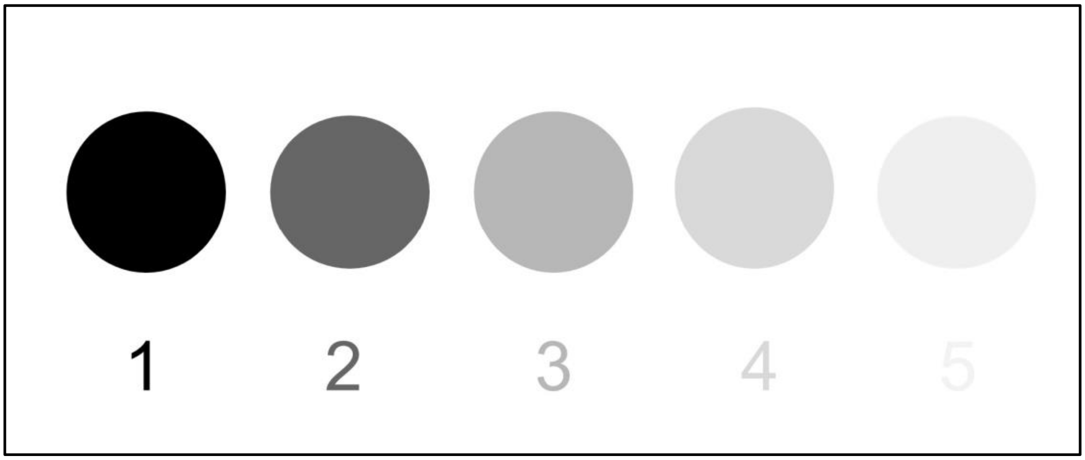

Figure 5: Scale for the optical test. The shade of the circle that can be seen through the oil changes based on the opacity of the oil. When the oil contains high levels of suspended solids, only the darkest circle is visible, and when the oil is transparent the lightest circle is visible.

3.3 Centrifuge Experimentation

For our experiments, we used resources at the Dead Sea and Arava Science Center at Kibbutz Yotvata. We used two centrifuges, both manufactured by MRC. The first centrifuge, MRC CN1050, can process up to two hundred milliliters of liquid in 4 x 50 mL test tubes at up to 5750 RPM (rotations per minute). This first centrifuge was used for preliminary testing. Four 45 mL samples were spun in the centrifuge for an hour at maximum speed. One vial was removed every fifteen minutes, except at the 45-minute mark, to test clarity and change in volume. The second centrifuge was an MRC LCEN-402N, which can process up to two hundred milliliters of liquid in 4 x 50 mL test tubes at up to 4000 RPM. For our second test, four samples of oil were spun at 4000 RPM in this centrifuge. We removed one vial of oil every fifteen minutes, and an equivalent vial of water was substituted. The results from the samples were collected and recorded in a spreadsheet. The sediment mass was measured by recording the vial's initial mass and the mass of the vial with the sediment, then finding the difference.

Chapter 4: Separation by Gravity: Results and Data Analysis

4.1 Gravitational Settling Results

The rate of natural oil separation, using gravity, approximates logarithmic behavior. The layer of solids at the bottom of the container quickly increased in volume at the beginning of the test, and the rate of growth slowed down as time passed. These results are shown in Figure 6. As the trials continued, the rate of separation slowed rapidly after day 3, reaching a plateau after day 11.

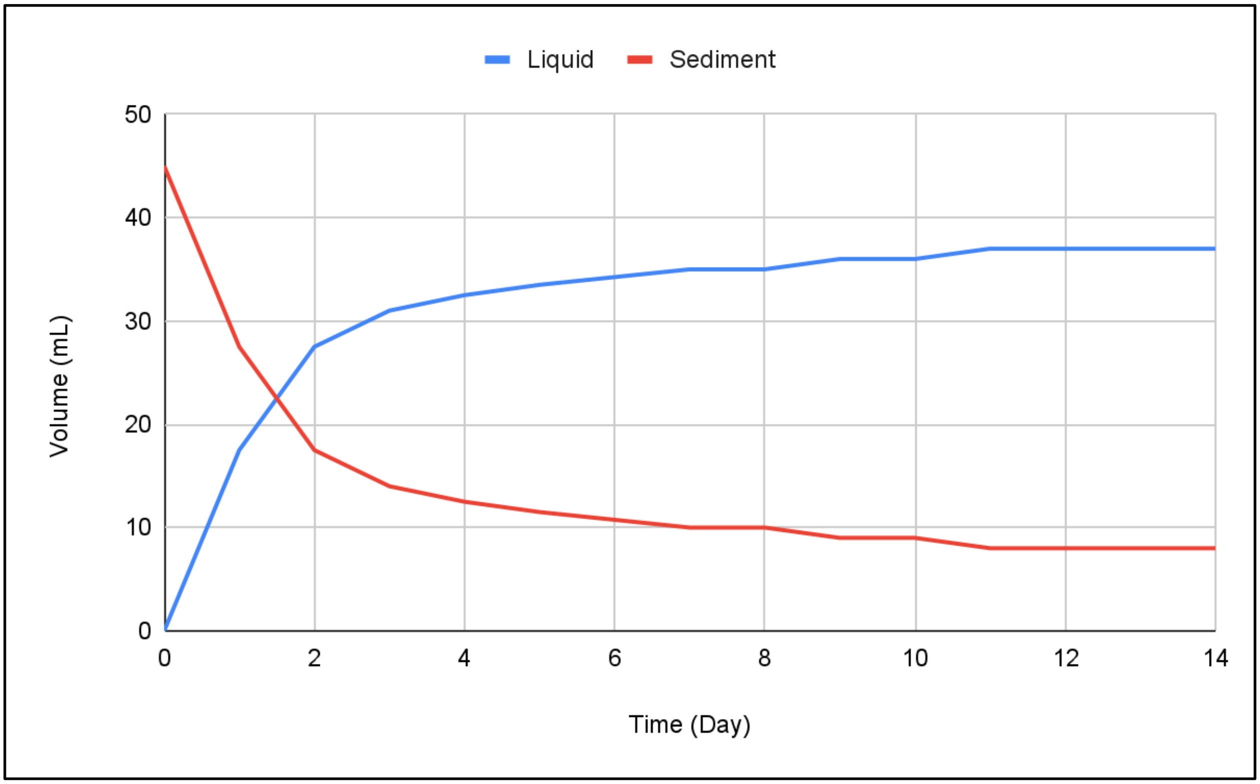

Figure 6: Oil separation over time separated by the gravitational method. This graph shows the recorded volumes of the two phases daily for 14 days.

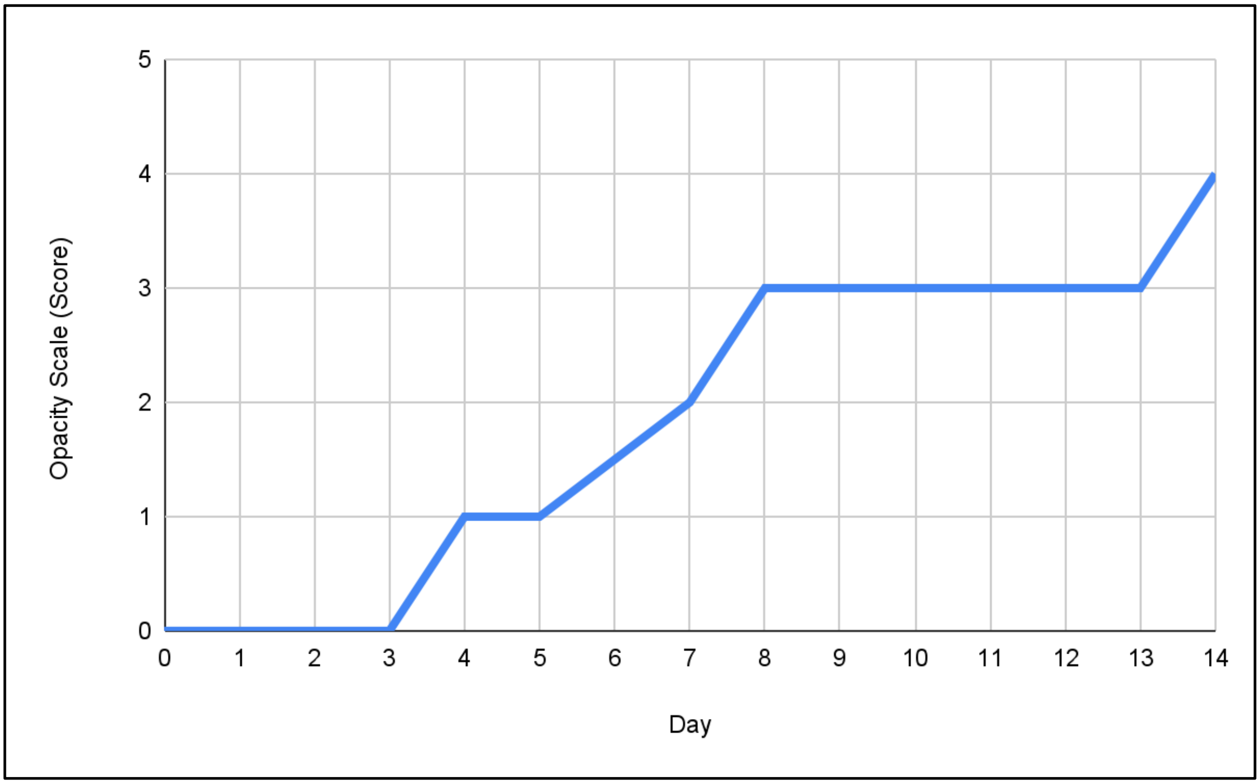

Figure 7: Optical scale for the gravitational method. The graph shows how the clarity changes after each day.

For the first three days of the gravitational test, the sample recorded zero on the optical scale, appearing opaque. The clarity of the oil began to improve between days four and eight. As seen in Figure 7, the opacity test showed that the gravitationally separated oil followed a logarithmic trend. Despite reaching a score of four, the sample did not become completely transparent during our tests which required a score of five.

4.2 Gravitational Settling Discussion

The initial change in liquid volume during the separation process was due to the larger sediment settling first, faster compared to the smaller particles. As a result of this separation, the liquid changed rapidly in clarity and color, transitioning from an opaque, pasty brown color to a translucent, medium-yellow hue. The translucence of the sample was due to the presence of smaller, less dense sediments still suspended within the oil. These sediments sink at a slower rate, and contribute a small volume to the liquid, resulting in no visible change in sediment volume growth (Majekodumni, 2015). This is shown by the slow increase in sediment volume in Figure 6. However, once these smaller solids settled, the oil cleared significantly, attaining an optical score of four. The majority of solids had settled and clarity was gradually increasing at a slower rate, as indicated by the plateau between days eight and thirteen. To achieve an optical score of five, further experiments could involve leaving oil samples to settle for an additional week. Based on the observed trend, an optical score of five could be reached after three weeks.

Chapter 5: Separation by Centrifuge: Results and Discussion

5.1 Results from the Preliminary Tests

The preliminary tests show that the oil fully separated after an hour. Figure 8 shows clear oil after an hour of centrifugation at 5750 RPM, demonstrating the centrifuge's effectiveness.

Figure 8: 45 mL sample of oil spun at 5750 RPM for one hour. This figure demonstrates how a sample should look at opacity level 5. The solids are visible at the bottom right of the container.

The trials at fifteen, thirty, and sixty minutes had opacities of levels two, three, and five, respectively. The final result was transparent, with little to no suspended solids to cloud the clarity. Figure 9 shows the opacity results over time.

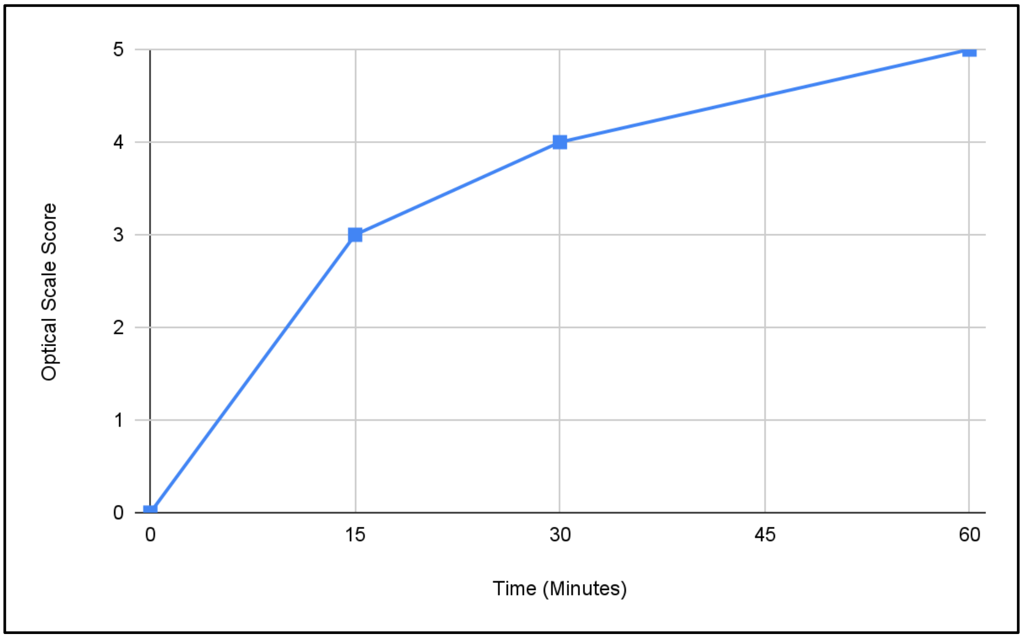

Figure 9: The relationship of oil clarity vs time when spun at 5750 RPM. From 0 to 15 minutes, the oil rapidly becomes clearer but slows down after 30 and 60 minutes, reaching optical scores of 4 and 5, respectively.

5.2 Results from Final Experimentation

After using the second centrifuge, model LCEN-402N, the oil fully separated within an hour of centrifugation, as seen in Figure 10 below.

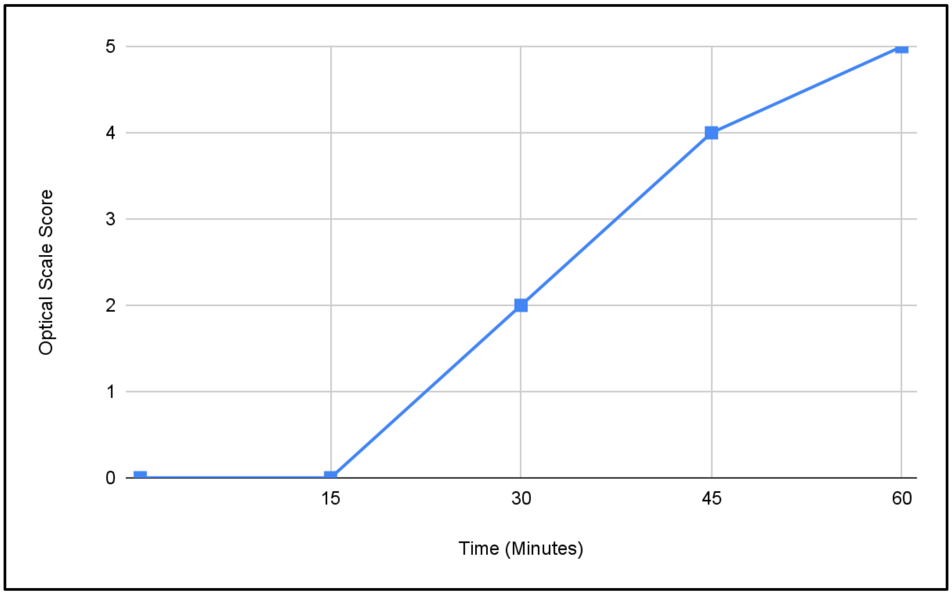

Figure 10: Graph of the change in clarity from the oil in the centrifuge over time at 4000 RPM. The first fifteen minutes show no visible change in clarity, but the sample steadily became clearer and was completely transparent after sixty minutes.

At 4000 RPM, the oil progressively became clearer, following the logarithmic trend. After fifteen minutes of centrifugation, none of the numbers from the optical test were visible, which resulted in a score of zero. At thirty minutes, the liquid was partially clear and received a score of two on the optical scale. After 45 and 60 minutes, the samples scored a four and a five on the optical scale, respectively, with five being fully clear. Table 1 below shows the recorded data from each trial at 4000 RPM. The recorded data includes the mass of the solids, the volume, and the clarity of the oil after its time in the centrifuge.

Table 1: Data collection from samples spun at 4000 RPM

Time	Sediment (g)	Liquid (ml)	optical scale (1-5)
15	5.84	39	0
30	5.64	39	2
45	5.94	40	4
60	5.9	40	5

5.3 Centrifugal Separation Discussion

The results from the preliminary tests demonstrated that a centrifuge effectively separates the oil and sediment much faster than the gravitational method. We only obtained results from the preliminary tests for fifteen and thirty minutes due to the centrifuge malfunctioning. Further testing can determine the clarity after 45 minutes.

In the different runs of the centrifuge, we found negligible variation in the volumes of oil and solids during the various trials. As seen in Figure 11, the sample was not clear enough after fifteen minutes to see the darkest circle in the opacity test. Additional small sediment remained in the oil after this run, possibly due to the particles' low density and small size (Majekodumni, 2015). After thirty and sixty minutes, the oil clarity improved, implying we found fewer suspended solids.

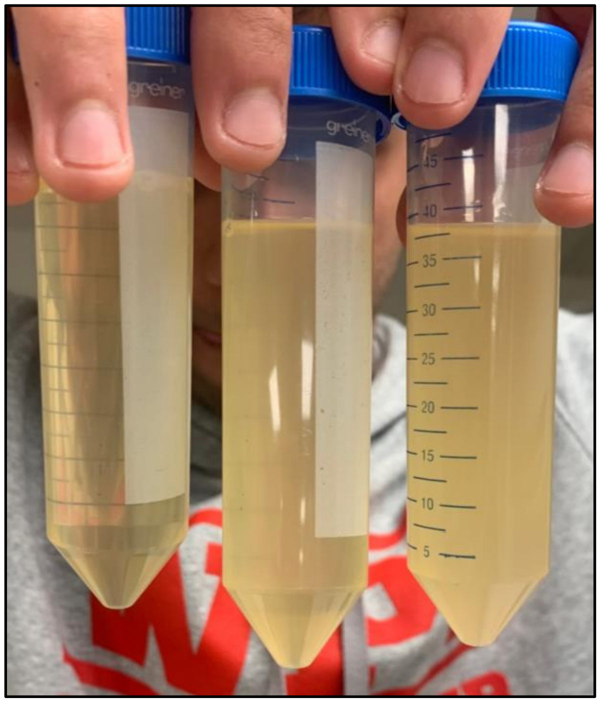

Figure 11: Samples that ran in the centrifuge for 15 min (right), 30 min (center), and 45 min (left). This figure shows how time in the centrifuge affects the opacity of each sample.

We found that the centrifugation method followed the same logarithmic trend as the gravity method, with a faster separation rate. After fifteen minutes, a large amount of sediment had separated, but the oil was still cloudy. Figure 11 shows how the samples in the experiment have similar volumes but different opacities. As shown by our results, oil samples only need to be run at 4000 RPM for one hour to achieve satisfactory clarity. Further testing will provide a better understanding of sediment and oil separation rates at different speeds.

5.4 Preliminary Discussion

The sample spun in the centrifuge for one hour at 4000 RPM had no sediments fall out of suspension after a week. This finding indicated that the centrifuge process removed all of the sediments in the sample. This is an improved result compared to the current method because after being decanted, the gravitationally settled oil still had suspended particles settling to the bottom after a few days. This result demonstrates that the samples obtained from the centrifugation method are separated more effectively than the oil samples derived through gravity alone. This new method produces a higher quality product than the oil processed by gravitational separation which our sponsor can sell to the kibbutz and other locations.

If our sponsor invests in a centrifuge for his process, we recommend a centrifuge that can operate above 4000 RPM to ensure the safety and longevity of the machine. If used at maximum RPM for an extended period of time, the machine experiences high strain, which could lead to premature failure. A centrifuge rated for a higher RPM can easily operate at 4000 RPM, which prolongs its service life. The size and weight of the centrifuge should be able to fit on a tabletop or benchtop because this is a pilot process, and portability and size are important considerations.

However, centrifugation does not need to be the only method used when processing oil. Combining centrifugation and gravitational settling is an option for Kibbutz Ketura that allows for the collection of oil-rich solids for sale. These solids can sell to spas and similar businesses for massages and skin treatments. If these methods are combined, the oil will be allowed to separate for approximately three days to allow most of the solids to settle out of suspension. The remaining cloudy oil is then poured off and centrifuged, leaving a solid and clear oil for sale.

Chapter 6: Further Discussion and Recommendations

6.1 Centrifuge and its potential breakthrough

Our results show that a centrifuge can accelerate the separation process. The oil takes around three weeks to settle through gravitational settling, while the centrifuge can achieve better results within one hour. We have reached our goal of accelerating the process, and these findings can help change the outlook of the global argan industry.

Argan oil is an emerging product in the cosmetic industry, attracting the attention of major corporations that anticipate its global impact. The argan market is projected to double its current value to approximately 700 million USD by 2030. The growth would require increased production of argan oil to meet market demand. Larger companies, such as OLVEA, will have little difficulty scaling to this production, however, Kibbutz Ketura can not join these leading companies due to their current method of argan oil production (Grand View Research, n.d). Our efforts to improve the efficiency of oil separation have enabled this pilot project to move closer to competing with larger companies. Our efforts can also influence other local and small-scale argan oil producers as well.

6.2 New Innovations to the Israeli Industry

The global demand for high-quality oil can be matched with a new supply from this emerging industry in Israel. If more kibbutzim and farms invest in argan, there is a greater financial incentive to open a factory in Israel to ensure standards of quality and increase the efficiency of production. These developments could lead to argan becoming a major export of this region if produced on a larger scale.

The centrifuge offers another valuable benefit to the argan industry by entirely removing the sediment left behind in the oil. These sediments may lead consumers to view the product as low quality because they are considered unwanted impurities. By utilizing a method that can produce higher-quality oil, companies can more confidently incorporate argan oil into their product. This new method can lead to increased production of high-quality argan oil products.

Furthermore, our sponsor's research on identifying argan trees with the highest oil content presents an opportunity for collaboration with the company Sivan. Sivan has conducted thorough research and developed a tree that yields more nuts than the average argan tree. If our sponsor collaborates with these researchers, they could create a genetically modified tree that produces large amounts of nuts with high oil content. This would greatly impact the argan industry, expanding the oil-making capabilities of argan fruit by increasing supply.

6.3 Future of Labor in the Argan Industry

The different labor conditions at the kibbutz and across Israel have forced argan oil production to change. Hiring workers in Israel is expensive due to the required benefits, which makes large-scale manual labor operations uneconomical (Adler, 2011). If the plant at Ketura scales up, the current method would require large amounts of manual labor. This would result in less profit from the oil, even with increased oil production. To make this production economically feasible, the traditional process must be adapted to Israel, specifically kibbutzim.

The centrifuge not only produces oil faster but can provide a less labor-intensive solution for separation. This finding is one of the first steps in creating a functional argan industry in Israel. Further testing could find alternative solutions to other stages in the argan oil-making process. With these innovations, argan oil can become a profitable industry in this region.

6.4 Sharing the Argan Market

As the market for argan oil expands in Israel, there is a potential for Israel to become a notable exporter of argan oil. This could affect the Berber argan oil production by outpacing their supply rate and causing the oil to be cheaper. However, our sponsor is not aiming to interfere with the Berber lifestyle or their products.

A kibbutz and the Berber women both share the ideals of working as a community to produce something. The Berber community sells to larger corporations such as L'Oreal. Our sponsor wishes to sell to different kibbutzim in the area and possibly spas or hotels. Due to the difference in the market, both communities can sell the oil and not hinder the other. To further prevent interference between the two producers, the different oils can be labeled according to whether it is made traditionally or in the lab. Hand-made oil products can be labeled as such for Berber women, while centrifugal oil can be labeled as lab-produced oil. However, it is important to note that there is no physical difference between these two oils, and both provide the same benefits when used.

6.5 Recommendations

We assessed three MRC brand centrifuges, namely the LCEN-402N, CENLBN-400ML, and CENHBN-2L, and examined their advantages and disadvantages. Our evaluation criteria included cost, maximum RPM, scalability, compatibility with the sponsor's current scale, and durability. Our sponsor is currently producing 4 liters of argan oil per month and has plans to scale to 10 liters per month in the near future. The LCEN had the lowest cost and was compatible with the current scale. Some drawbacks of the LCEN include the lowest maximum RPM, low scalability because of its low volume capacity, and low durability. The CENLBN had a median cost, durability, and volume capacity, and was compatible with the current scale. It had a higher maximum RPM than the LCEN, making it more scalable. The CENHBN was the largest centrifuge, with the highest cost, highest durability, and highest volume capacity, but had an equivalent maximum RPM to the LCEN. To determine the best centrifuge to purchase, we developed a centrifuge decision matrix, comparing each centrifuge based on each criterion, as shown in Table 2. In the table, the number ten means the item fits the category the best, while one means it is impractical for the category.

Table 2: Centrifuge decision matrix. This is based on cost, max RPM, scalability, current scale, and longevity

	Cost	Max RPM	Scalability	Current Scale	Longevity	**Total**
LCEN-402N	10	8	3	7	3	**31**
CENLBN-400ML	5	10	4	8	7	**34**
CENHBN-2L	2	8	10	3	10	**33**

From our results, we recommend that our sponsor buy an MRC CENLBN-400ML, which can process 400 milliliters per cycle. This centrifuge would be preferred due to its ability to spin at a high rate and is best suited for Ketura's current and scalability. The MRC CENLBN-400ML centrifuge and rotor cost 10,266.60 NIS (2,793.82 USD). This centrifuge would be a sound investment due to the high-profit margin of argan oil and the short time to recoup the investment of a new machine.

Chapter 7: Conclusion

Our goal was to accelerate the separation process of argan sediment from the oil to increase the production of argan oil at Kibbutz Ketura. Tests performed between the gravitational and centrifugal methods showed that the centrifuge separated the oil at a faster rate. The MRC CENLBN-400ML is the recommended centrifuge due to its high oil capacity and ability to process samples at high speeds. With this centrifuge, our sponsor can comfortably scale up to and past their goal of ten liters of oil produced per week.

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