A Tough Nut to Crack:
Evaluating Alternative Argan Nut Cracking Methods for Kibbutz Ketura

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ABSTRACT

The Kibbutz Ketura community located in Israel's Negev desert is working to supplement their date orchards with argan trees. To produce argan oil, kernels are extracted from the argan nut. The nut cracking machine at Kibbutz Ketura cannot reliably crack large argan nuts, pulverizing nut kernels, rendering them unusable for oil production. We explored argan nut preprocessing techniques such as soaking and pressure cooking to improve kernel yield from large nuts.

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AUTHORSHIP

Maria del Carmen Sacristan Benjet, Peter Nikopoulos, Amanda Schnapp, and Jean Claude Zárate all contributed to the research, writing, and editing of this Interactive Qualifying Project (IQP) report.

Maria del Carmen Sacristan Benjet initially wrote the Introduction and contributed towards the Agricultural Economy of Israeli Kibbutzim, and the argan nut cracking patterns and preprocessing methods section of the Background. Additionally, she informed the mechanical theory of the argan nut properties of the Results. Carmen made additional contributions by editing the Methodology, Results and Discussion, and Conclusion sections.

Peter Nikopolous made his largest contributions to the Methodology, Results and Discussion, and Conclusion sections of the report. Peter also edited the Introduction, Background, Methodology, Results, and Conclusion sections of the report. Peter conducted the preprocessing experiments with the assistance of Amanda Schnapp.

Amanda Schnapp contributed towards the Methodology, Results and Discussion, and Conclusion sections of the report. Amanda initially wrote the experimentation subsections of the Methodology section and the physical preprocessing results within the Results and Discussion section. Amanda helped edit the Introduction, Background, Methodology, Results and Discussion, and Conclusion sections. Amanda also accompanied Peter with conducting the physical experiments on the argan nuts.

Jean Claude Zárate wrote the Introduction and made contributions to the Background and Methodology and wrote the subsections on Nut Cracking in Kibbutz Ketura and Cracking Devices. Jean Claude made additional contributions by editing the Background, Methodology, Results and Discussion, Conclusion, Acknowledgements, and Authorship sections.

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INTRODUCTION

Kibbutz Ketura is an agricultural-based community located in the Arava desert a half hour north from Eilat. The community is responsible for six percent of Israel's date production, but is looking to shield itself against potential downturns in the date market and water scarcity. Therefore, Kibbutz Ketura is interested in diversifying from its reliance on date fruit exports, which constitutes two thirds of the community's revenue. In the 1970’s, Dr. Elaine Solowey of the now Arava Institute of Environmental Studies at Kibbutz Ketura, began experimenting with growing argan trees at the Kibbutz to determine its viability in a desert climate with brackish water.

Argan oil, which is produced from the kernel of the argan nut, has a well - established international economic market valued at over 224 million USD with eleven percent year-over-year growth projected for the next decade (Argan Oil Market Size, Share & Trends Analysis, 2020). Argan trees utilize less water per tree than date trees making them more resilient in the desert climate.

To produce argan oil, the fruit of the argan nut must be put through peeling, cracking, and extraction processes. The fruit of the argan tree is peeled to access the shell of the nut. The argan nut shell is extremely hard to crack, even withstanding being run over by a car. Each argan nut is forcefully cracked open to release one to five kernels per nut. These kernels are then processed to produce the argan oil. Argan nuts are cracked at Kibbutz Ketura using a machine which struggles to operate under the variety of argan nut shapes and sizes. This machine fails to crack the large argan nuts fifty percent of the time, crushing the kernels and rendering them unusable for later stages of oil production.

Kibbutz Ketura’s argan nut orchard is currently in a pilot phase producing only 1500kg of fruit per year and thus they are still determining the best practices for argan nut production. Production of argan nuts at Kibbutz Ketura is expected to double every year. Given the difficulties associated with cracking argan nuts the goal of our project was to explore preprocessing methods that can improve the argan nut cracking process and boost the overall agriculture income of the Kibbutz. We determined the effects of soaking, boiling, pressure cooking, freezing, piercing, and scoring the argan nuts prior to cracking them. Preprocessing methods that induced microfractures within the argan nut shell proved to be most effective at properly expelling the argan nut kernels. Soaking and then pressure cooking the argan nuts had the greatest effect on reducing the force necessary to crack open the nut. These microfracturing preprocessing methods could be implemented at Kibbutz Ketura to help improve the kernel yield of their current nut cracking machine.

BACKGROUND

Kibbutz Ketura, an agricultural-based community, is looking to diversify their crop production and are running a pilot program with *Argania spinosa* as a new sustainable commercial crop. Diversifying away from a dependency on dates towards a less water dependent argan crop would protect the Kibbutz against water scarcity and threats to monocultures. The Kibbutz would grow argan locally and process it into oil locally. One necessary step in the argan oil production process is the cracking of the nut to extract the kernels. Kibbutz Ketura uses a nut cracking machine that can crack small argan nuts well, but does a poor job of properly cracking large argan nuts. Large argan nuts are classified as nuts that have a diameter fifteen millimeters or greater. While the large argan nuts are currently a minor portion of the harvested nuts, it can be expected that the maturing argan trees will yield larger nuts in the future (N. Solowey, personal communications, Nov. 23, 2020), since they are selectively bred with other large nut yielding crops. Therefore, Kibbutz Ketura is interested in developing a low-cost solution to handle the full range of argan nut sizes with minimal loss of kernels. Due to the promising economic potential of the argan oil market, creating reliable ways to extract argan nut kernels is important, since the current machine wastes fifty percent of the large nuts.

The Agricultural Economy of Israeli Kibbutzim

Ever since Zionist pioneers came from Europe, Jewish people have been working hard to revitalize the land of Israel and support themselves with an agricultural economy. The Zionist dream of an agrarian society drove the foundation of Israel. An emphasis on establishing food security, water development, and technological innovation allowed these pioneers to manifest the Zionist agricultural dream. This dream took the form of Kibbutzim.

As of 2019, there were 270 Kibbutzim scattered throughout current day Israel (Reisinger, 2019). Kibbutz Ketura is located in the south of Israel in the Negev desert region (see Figure 1).

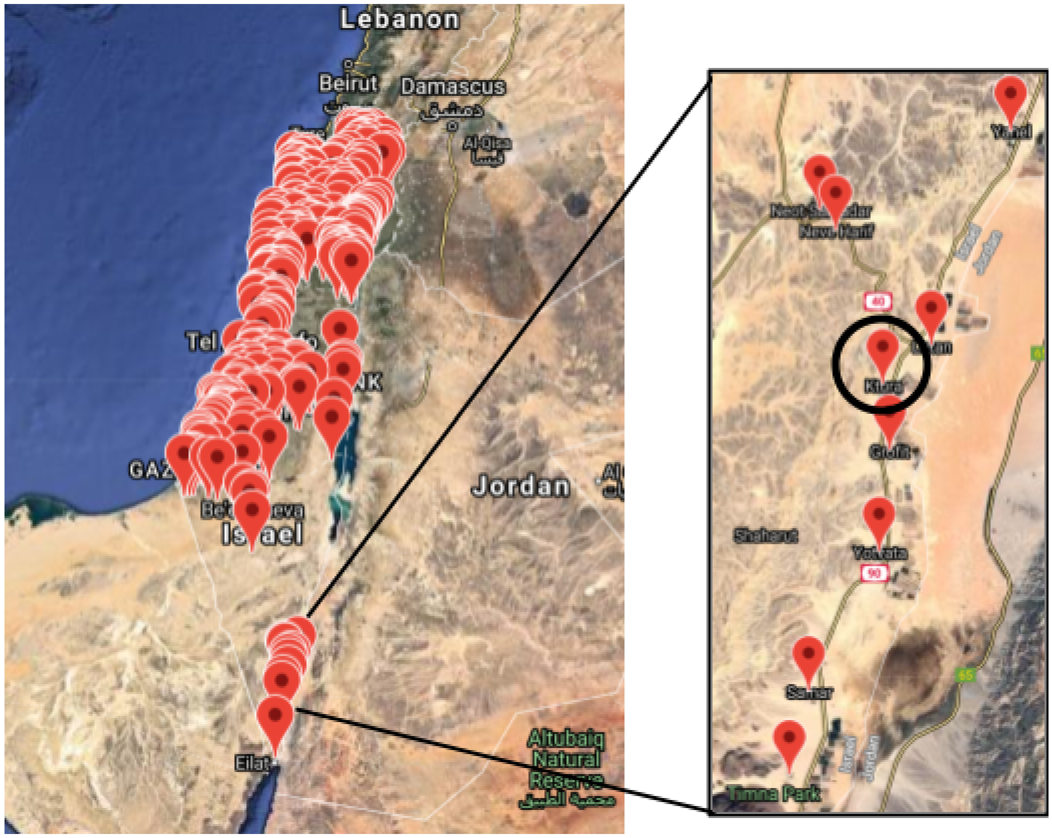

Fig 1. Satellite imaging of the active kibbutzim in Israel. Kibbutz Ketura is circled in black. (*kibbutzim map, 2020)*

The majority of Kibbutz Ketura's income comes from their agricultural projects, although tourism and accounting services also contribute to this sum (*N. Solowey, personal communications*, Feb. 22, 2021). Kibbutz Ketura maintains over 12,000 date trees producing up to 140 kilograms of fruit per tree per year (N. Solowey, personal communications, Nov. 23, 2020). Kibbutz Ketura produces six percent of Israel's thirty-thousand metric tons of date fruit produced a year. Similar to other Israeli Kibbutzim, farming and processing these date trees has been an important aspect of the Kibbutz Ketura economy. While these fruit trees have been successful in the past, the changing and unpredictable environment of the Arava Desert makes Kibbutz Ketura's dependence on these water-heavy crops risky. Kibbutz Ketura's interest in diversifying against water scarcity and other threats to agricultural production has led them to explore cultivating crops such as argan trees.

For any reliable and sustainable source of agriculture to exist in the arid climate of southern Israel, the crops must be well supported by irrigation techniques and well-maintained soil. Water scarcity in southern Israel will continue to bottleneck farmers from increasing the size of their farms. Within the past decades, Israeli farmers have seen less support from the government and water prices have increased. This is especially troubling as fifty percent of all agricultural land in Israel is composed of irrigated crops (Ben-Gal, 2006). It seems that the struggle for farmers to secure reliable water sources will likely continue. Finding a way to make the most out of the resources currently available is vitally important to many of Israel's Kibbutzim.

Argan oil has a well-established international economic market. As of 2019, the international argan oil market was valued at 224 million USD and is expected to grow by eleven percent year-over-year in the upcoming decade (Argan Oil Market Size, Share & Trends Analysis, 2020). Argan oil can be sold for as much as 300 USD per liter (Ash, 2020). This expensive and highly sought after oil is used in medical, cosmetic, and food products worldwide. The largest producer of argan oil in the world is Morocco as the *Argania spinosa* is native to the country. In Morocco, argan oil production is mostly done by hand using cheap labor, an option not available to the kibbutz. Due to the prevalence of manual labor, there has been no industrialized process developed to extract the argan nut kernel. With a thriving commercial market, argan trees have the potential to become Israel's sustainable alternative crop and could help diversify the Kibbutz's agricultural endeavors. However, Kibbutz Ketura will have to innovate a new process for successfully extracting the argan nut kernels.

Nut Cracking in Kibbutz Ketura

At Kibbutz Ketura, argan fruits are harvested and the nuts are extracted, making them ready for cracking. The first stage of the argan nut cracking process involves manually sorting the nuts into size categories of eleven, thirteen, fifteen, and eighteen millimeters in diameter using sift-like boxes. Afterwards, the sorted buckets of nuts are fed by hand into the argan nut cracking machine (see Figure 2). The current machine consists of two metal plates, one stationary and one rotary, and that applies enough force to crack the shell of the argan nut. Once the argan nuts are cracked, the inner kernels must be separated from the broken outer shells. The kernels then go through an oil press to create the argan oil.

Fig 2. A still from a video by Nadav Solowey showing the current argan nut cracking machine in use at Kibbutz Ketura.

Even though the argan nuts are carefully stored and sorted into batches by diameter, the cracking machine is not well equipped to handle the variety of sizes within a sorted batch. The distance between the machine plates can be adjusted for the different size nut batches. While this technique helps reduce the inefficiency stemming from the large range of argan nut sizes, it is inadequate. For argan nuts less than fifteen millimeters in diameter, six to eight percent of them are completely crushed in the process. For larger nuts, half of them are crushed when going through the machine, rendering them, and their resulting kernels, unusable for the later stages of the argan oil production process. On some occasions, only a partial crack is achieved by the machine and the shell will entrap some of the argan kernels within. The partially cracked argan nut would then have to be processed through the machine again to potentially access the stuck kernels, resulting in an increased likelihood that the desired kernels will be crushed.

Currently 10-15 percent of the argan nuts are classified as large nuts during the sorting process prior to being stored by size. The large nuts are more often processed through the machine multiple times, resulting in about fifty percent of the kernels being crushed and wasted. The loss rate for the large nuts is far above the ten percent range of acceptable losses set by the Kibbutz. An analysis of the varieties of argan trees in the orchard estimates that in the future fifty percent of the argan nuts will be classified as large nuts (N. Solowey, personal communications, Feb. 4, 2021). This means that the Kibbutz is at risk of losing over twenty five percent of all harvested nuts during the cracking stage of argan oil production if they continue to utilize their current machine without further modifications.

Argan Nut Cracking Patterns and Preprocessing Methods

The argan nut, and more specifically the outer shell, is incredibly tough. The hardness of the nut proves difficult for many industrial nut cracking machines, utilizing proper orientation alleviates this difficulty. Argan nuts have a preferential cracking direction, parallel to the nut seam. N. Solowey found in his preliminary argan nut cracking tests that stress along the vertical axis seen in Fig. 3, releases the nut kernels in their entirety more easily. Loading the nut vertically takes advantage of the nut seam, which is a weak point in the nut shell. Since the seam runs the entire length of the nut this also allows the nut to fracture open completely into two neat pieces. The argan nut seam is pictured below in Fig 4. Attempting to crack the nut horizontally more often results in cracking the inner kernels. Additionally, the oval shape of the nut adds to the difficulty of cracking since it distributes the force evenly throughout the shell, and thus decreasing stress in any one particular point.

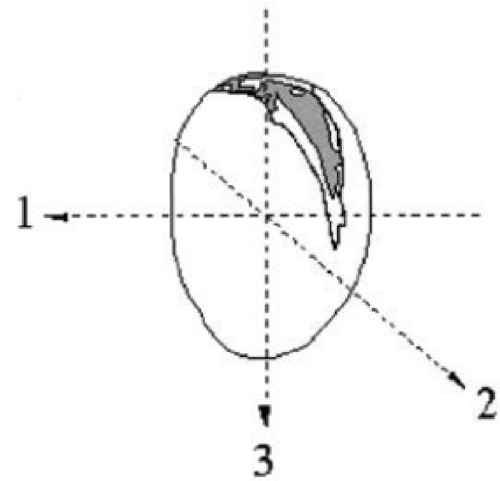

Fig. 3. Representation of three possible directions for the argan nut compression. (Kisaalita et al, 2010)

Fig. 4. The light brown strip of material down the middle of the nut is the seam.

To crack an argan nut, stress needs to be applied to cause strain on the nut shell. The shell is only capable of withstanding a certain amount of stress until eventually the yield point is reached and the nut shell will deform. Eventually, the nut will no longer be able to continue to be elastically deformed and fractures will start to occur. Fracture toughness "is an indication of the amount of stress required to propagate a preexisting flaw" (*Nondestructive Evaluation Physics : Materials*, n.d.). Argan nuts have a low fracture toughness, meaning that when stress is applied by the cracking device, a fracture forms and quickly spreads. This spreading of microfractures causes the nut to crack in a rapid fashion. This explosive cracking characteristic of the argan nut is highly undesirable as it leads to high kernel loss.

There has been research done to study the physical effects of preprocessing methods on other types of nuts, although these procedures are often not tailored towards argan nuts. Ogunsina & Bamgboye (2013) found that regardless of whether you crack a cashew nut longitudinally or laterally, the force required to fracture the shell of the cashew nut can be reduced by steam-boiling the cashew and by roasting it. Similarly, Ebunilo & Ojariafe (2014) found that heating palm nuts to temperatures between 170 and 180 degrees Celsius before cracking them made the shell more brittle. Fiotetti (2016) anecdotally explains that chestnuts can be easily cracked at home by pressure cooking them for fifteen minutes. Likewise, Stevens (2014) anecdotal cooking website claims that the key to cracking pecan nuts is pressure cooking for five minutes. Additionally, Gallegos & Suministrado (2013) found that in pili nuts "the force required to initiate shell fracture generally decreased with an increase in nut moisture content." Although these methods do not involve argan nuts, these procedures can be applied to cracking any nut shell. As such, we hypothesized that soaking the argan nuts for a long period of time may reduce the hardness of the shell. For argan nuts specifically, Nadav Solowey found that roasting the nuts makes them easier to crack, however it unfavorably changes the flavor of the oil produced and is therefore not a viable preprocessing technique.

The current machine at Kibbutz Ketura does not take into account the orientation of the nut, but a machine that does could result in a better kernel yield. Since the Kibbutz is still in the pilot stage, it is not currently in a position to heavily invest in buying or designing a new machine that takes orientation into account. Thus we are examining pre-processing methods that may increase kernel yield for the current machine.

METHODS

Currently, Kibbutz Ketura is using a commercial machine to crack argan nuts. However, when processing large argan nuts, the machine pulverizes fifty percent of them. The Kibbutz expects that the ratio of large argan nuts per harvest will grow to be one out of every two nuts harvested in the upcoming future. Therefore, Kibbutz Ketura is in need of a superior argan nut cracking method to preserve the inside kernels of large nuts. The project explored preprocessing techniques that prove effective in both improving argan nut kernel yield and reducing the force required to crack argan nuts.

Cracking Device Baseline

We identified three manual nut cracking devices on Amazon that worked distinctly from each other and purchased them to be shipped to our lab. These are the Landtom Premium Metal Nutcracker (with a squeezing mechanism), the Anwenk Nut Cracker Tool Heavy Duty for All Nuts (with a screw mechanism), and the 8MILELAKE Desktop Wood and Metal Heavy Duty Nut Cracker Gadget Tool (with a lever mechanism).

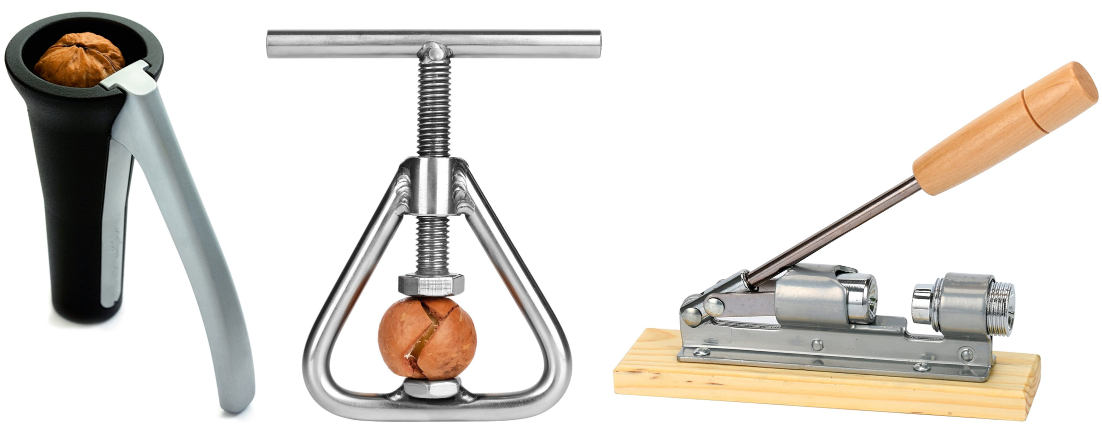

Fig. 5. (Left to Right): The Landtom Nutcracker device with a squeezing mechanism, the Anwenk device powered by a screw component, and the 8MILELAKE Nut Cracker Gadget with a lever mechanism.

The cracking ability of each of the devices were tested on ten unaltered control argan nuts to provide a baseline for future comparisons. The lever device failed to crack the argan nuts and therefore was excluded from further tests. These cracking devices were tested and compared on several categories in order to assess their ability to crack argan nuts.

Preprocessing Experiments

The preprocessing methods we tested consisted of soaking, boiling, pressure cooking, freezing, scoring, and puncturing the argan nuts. We explored the effect of different pre-treatments to determine if they would either reduce the force needed to crack the argan shell or improve the likelihood that kernels are expelled.

For the soaking experiments, six argan nuts were allowed to soak in water for differing amounts of time; thirty minutes, two hours, one day, and one week. A weight was used to fully submerge the argan nuts. The argan nuts were cracked by both the screw and squeezing devices immediately after soaking. Device data for the soaked argan nuts was compiled and recorded.

For the boiling experiments, six argan nuts were placed into a pot of boiling water on an electric stovetop for the following times: fifteen minutes, thirty minutes, one hour, and two hours. The argan nuts were removed from the boiling water and dried on a paper towel. Similar to the soaking protocol, the boiled argan nuts were immediately subjected to the same cracking methods.

For the pressure cooker experiments, we filled a pressure cooker with 250 milliliters of water. We placed a metal rack on the bottom of the pressure cooker to separate the nuts from the heated surface of the pot. Finally, we placed six nuts inside the pressure cooker for each trial and sealed the lid. The nuts were pressure cooked for durations of one, two, three, and four hours on the "high pressure" setting. Afterwards, the argan nuts were extracted for further experimentation with the previously chosen nut cracking devices. This experiment was repeated for each of the four different times, similar to other experiments.

In addition to testing the effects of individual pre-processing methods on the argan nuts, we experimented with combinations of pre-processing techniques to potentially further induce microfractures within the nut shell. The first combination of techniques we tested was soaking and pressure cooking the argan nuts. The pressure cooker creates an increase in pressure by heating water into steam. Soaking the nuts before pressure cooking could allow for the water to vaporize inside the nut creating internal pressure to build up. This internal pressure applies tensile stress to the shell which could create microfractures.

For the freezing trials, twenty four argan nuts were first boiled for one hour and then placed onto a paper towel to dry off any excess water. Four groups of six argan nuts were then placed on a tray and placed into a commercial freezer. The freezing durations were four, six, eight, and ten hours. The argan nuts were removed from the freezer and any moisture on the shell's surface was dried off using a paper towel. The nuts were then allowed to thaw at room temperature (21°C), and each group of argan nuts were cracked by both the screw and squeezing devices. The resulting data was collected for each of the four durations.

Table 1: Summary of Physical Pre-processing Methods

Pre-processing method	**Number of Argan nuts per trial**	**Duration Times**
Soaking	6	½ , 2, 24, 168 hours
Boiling	6	¼, ½, 1, 2 hours
Pressure Cooking	6	1, 2, 3, 4 hours
Soaking + Pressure Cooking	6	1, 2, 3, 4 hours
Boiling + Freezing	6	4, 6, 8, 10 hours

Table 1. This table summarizes the physical pre-processing experiments that were performed on the argan nuts as well as the time durations used for each method. For each process, six argan nuts were used for each of the four trials.

We experimented with different scoring methods to observe the effect of manually introducing weak points into the shell. We scored each nut vertically using the edge of a file to create physical indentations in the shell. The nuts were scored between each nut seam. We ran trials with one, two, three, and four scores per group of six nuts. Each argan nut was loaded vertically on the screw device and scored in two categories: strength required to crack, and percentage of kernels released. The data was collected and compared below in Table 5 of the results section.

We tested piercing the argan nuts to observe how changing the area of cracking force applied to each nut effected cracking quality. To pierce the argan nuts, a hard screw was placed tip down on the top of each nut and then loaded into the screw device. A second trial was run where a second screw was placed in a similar fashion on the bottom of the nut. We used this configuration to experiment on six nuts in each trial, the effectiveness of the cracking was then recorded.

RESULTS AND DISCUSSION

Our experiments demonstrated the propagation of microfractures along the surface of the argan nut shell. Through proper exploitation of these microfractures, the overall cracking behavior of the argan nut could be improved. We found that scoring argan nuts improved the nuts' intact kernel yield. Furthermore, our experiments with soaking and boiling increased the fracture toughness of the nut shell, allowing for multiple fractures to develop before the nut is cracked. This opened the shell up more and resulted in a higher percentage of intact kernels being released. Pressure cooking dry argan nuts did not show any significant difference in cracking ease or kernel yield. However, pressure cooking soaked nuts showed impressive results; the internal pressure of the nut produced by the vaporizing liquid created large fractures on the nut shell. For future iterations of this project, we suggest testing for potential chemical changes within the argan nut kernel as well as continuing trials to expand upon our findings.

Device Baseline Testing

Our experiment trials showed that of the three devices, both the screw and squeezing devices were capable of cracking argan nuts while the lever device proved unsuccessful due to machine failure. The strengths and weaknesses of the successful devices are highlighted in Table 2.

Table 2: Device Baseline Testing

Cracking Device Function	Screw driven device	Squeezing device
Ability to crack nuts	YES	YES
Force required	3	1
Ease of loading nut	3	1
Ease of unloading nut	1	3
Kernel release percentage	90%	10%
Effective use of the nut seam	1	3

Table 2. This table is a comparison of the devices based on their demonstrated nut cracking properties. Each category is scored from 1 to 3, with 1 being the best and 3 being the worst.

The squeezing device was the easiest device to load nuts into and required the least amount of force to crack them; however, the lack of control over both the loading direction and the applied force caused the device to pulverize the majority of the control group. The squeezing device has no control over the way the nuts are loaded; since there is no method for it, the force is applied indiscriminately on the nut as opposed to consistently along the nut seam, causing the kernels to crack along with the shells. In addition to this, each nut required a tailored amount of force to crack without compromising the kernel. The squeezing device had no way to control this force, yielding inconsistent cracking results depending on the nut's physical properties. The lack of control over the force applied means that this device is unable to react quickly enough to take force off the nuts once they crack. Overall, the squeezing device scored very poorly with releasing argan nut kernels, succeeding only ten percent of the time on average (2 out of 19 kernels were released in testing). The main reason why the device had a high number of destroyed nuts (shown in Fig 6) was due to a lack of control over the applied force, which caused the device to crush the kernels along with the shell.

Fig. 6. A crushed argan nut shell and kernel as a result of no force control with the squeezing device.

The screw device was more successful, showcasing a reliable cracking performance stemming from its abilities to target the argan nut seam, and to control the force applied to the nut. While the squeezing device had no control over its applied cracking force, the screw device allowed for precise control over the force applied to the argan nut, resulting in a more reliable cracking experience.

With a ninety percent success rate, it released the highest number of intact kernels by far from each nut (18 out of 20 possible kernels were released in testing). Occasionally the kernels may be left in the shell after cracking, although this can be explained by irregularities in the nut shell. As exhibited by Table 2, it took more effort to perfectly align each nut in the screw device compared with the squeezing device. Despite this issue, the device was successful when the nut was oriented vertically (the ideal orientation for this device), creating a vertical split under the right amount of stress that secured a high success rate for releasing uncompromised kernels.

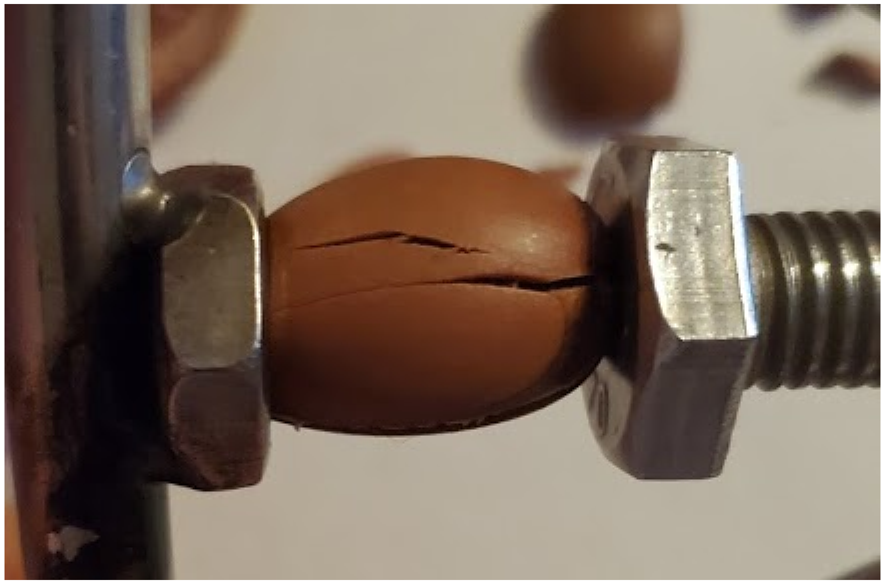

Fig. 7. Displays the vertical cracks that are created by the screw loaded cracking device. Vertically applied force will cause the shell to split along the cracks shown, the positioning of these cracks makes kernel release very reliable.

Preprocessing Results

Our experiments included six methods of altering the argan nuts to determine if we could modify the nut to increase the argan kernel yield. Argan nut soaking, boiling, and scoring revealed the creation of microfractures along the argan nut shell which determine the cracking behavior of the argan nut. When analyzing these results, one must take into consideration that the force required to crack each argan nut varies independently of the size of the nut. Our trials were conducted in batches of six to account for the variation, and the data was collected and presented in Table 3 below. The kernel percentage yield is calculated from the ratio of kernels released to total kernels. Many trials have a total kernel number greater than six, due to the fact that many argan nuts contain multiple kernels.

Table 3: Argan Nut Kernel Yield For Soaking and Boiling Trials

Argan Nut Kernel Yield	Trial 1	Trial 2	Trial 3	Trial 4	Baseline Kernel Yield
Soaked					
Kernel release screw device	7/8 **88%**	7/7 **100%**	5/6 **83%**	7/8 **86%**	**90%**
Kernel release squeezing device	0/8 **0%**	2/6 **33%**	4/8 **50%**	4/7 **57%**	**10%**
Boiled					
Kernel release screw device	6/7 **86%**	7/7 **100%**	7/7 **100%**	7/8 **87%**	**90%**
Kernel release squeezing device	1/7 **14%**	3/6 **50%**	4/8 **50%**	4/7 **57%**	**10%**

Table 3. This table illustrates the percentage of argan nut kernels properly released by the screw driven and squeezing devices for the soaking and boiling trials. Since each argan nut varies in kernel capacity, so the denominator for the ratios of each trial differ. The total percent yield of the argan nut kernels was then calculated using percent kernels released / total number of kernels. Baseline kernel yield is based off of the device baseline testing trial data.

Soaking argan nuts was one of the most promising protocols out of the preprocessing techniques. The most important relationship noted between the soaking times was how many full kernels were released per nut. Table 3 shows that using the squeezing device on soaked nuts if the nuts were fully soaked (over 2 hours) then the average kernel yield of that nut would be better than the control. The squeezing mechanism destroys ninety percent of all control group argan nut kernels when cracking, in this trial the squeezing mechanism would only destroy around fifty percent of soaked nuts. The screw device on the other hand, did not experience any kernel yield increase. Argan nuts soaked for longer than one day were cracked with less force when using the screw device when compared to the control group argan nuts. On the other hand, the squeezing device experienced little change in the cracking force of the soaked nuts.

When soaking the argan nuts, our team observed that some nuts would float, and after a few hours they would begin to sink, suggesting that the argan nuts are capable of absorbing water. Additionally, Fig. 8 shows air bubbles forming around argan nuts as they soak demonstrating the nuts ability to absorb water. The ability of the argan nut to absorb water suggests the existence of small pores along the argan nut shell. This water absorption takes time, which would explain why the kernel yield was only partially improved at two hours compared to the kernel yield at 24 hours.

Fig. 8. Soaking argan nuts that have been submerged for around fifteen minutes. Air bubbles are visible along the shell.

The longer the argan nuts were allowed to soak, the more the pores on the shell are filled with water. When a control nut is cracked, many small fractures are created along the shell, if no preprocessing methods are applied those cracks get larger, eventually resulting in the nut splitting open. When the nuts are soaked, water fills those small cracks allowing the cracking stress to be distributed across the rest of the nut, resulting in more small cracks. The soaking of the nut shell allows for multiple fractures to develop without achieving full material failure. Creating multiple fractures before failure allows for a higher percentage kernel yield because the cracked shell gets opened up more. This also reduces the force required to reach total failure stress, which may also help avoid crushing the kernel. Further investigation can be done to further understand why soaking the argan nuts seems to increase kernel yield.

We observed physical changes when boiling argan nuts. The water in which the argan nuts were boiled turned brown and the resulting kernels were wet to the touch. The kernels of these nuts were slightly darker when compared to the control group, indicating that boiling the nuts may have led to a chemical change in the kernel. This change could be an unfavorable side effect of boiling the nuts since our sponsor does not want to alter the chemical composition. Kernel color change was present when boiling the argan nuts for any duration longer than fifteen minutes. This is worth further investigation to determine if a chemical change did happen in the kernel or if the changes observed were purely physical.

Boiling the nuts in water seemed to fill the pores of the argan nut with water similarly to soaking the argan nuts. This affected cracking behavior of the boiled nuts in a similar fashion as it affected the soaked nuts. The biggest difference between the soaked and boiled nuts is that boiled nuts took a half hour to reach this state whereas soaked nuts took a day. Figure 9 pictures the shell fragments of a control nut and a nut boiled for thirty minutes. The control group nut splinters into pieces when placed in the squeezing machine, while the boiled argan nut split open releasing full kernels. Both the control and boiled groups required the same pressure to crack, but the result of the boiled argan nut cracks into a much neater end product. Testing with the screw device offered little difference in kernel yield because the kernel yield of the screw device was already so high. We recommend further testing what factors affect soaking and boiling times for the argan nuts. The size, shape, and buoyancy of each nut changes, so it is likely that different nuts may need more or less time to reach sufficient water absorption for optimal cracking.

Fig. 9. This photograph shows the argan nut shells after being placed into the squeezing device. The shell fragments on the left are from the control argan nuts, while the shell fragments on the right are from argan nuts that have been boiled for thirty minutes.

Scoring the outside of the nuts proved to be very successful. Three or four of these scores along the outside of the nut results in kernels to be released much more easily, meaning they were rarely left inside the shell. Furthermore, scoring the nut caused the force to crack the nut being significantly reduced. Scoring the nuts was successful because it manually introduced weak points into the argan nut shell. These weak points act in a way that allows for the applied force to be concentrated on the scored sections of the shell, allowing one to control where fractures form on the nut. Table 4 highlights the change in force to crack the nut and the number of kernels released as the number of nut scores increased.

Table 4: Mechanical Experimentation: Scoring With Screw Device

Scoring nut effectiveness	One Score	Two Scores	Three Scores	Four Scores	Screw device control
Force required to crack nut	5	5	3	3	5
Number of kernels released (screw device)	5/6 **83%**	5/8 **63%**	9/9 **100%**	8/8 **100%**	**90%**

Table 4. This table illustrates the percentage of argan nut kernels released for each of the four scoring trials, as well as the overall force required to crack the nut itself. To illustrate cracking force, each trial is rated 1-10, A lower score in each category means better performance, with 5 being average. Similar to the previous table, the baseline kernel yield percentage was based off of the baseline testing data of the screw device.

We also found that scoring along the existing seam of the nut did not make significant improvements to the cracking behavior of the nuts compared to not scoring the nuts at all. Therefore, to improve the results for each nut, we recommend scoring in the middle of each full shell section as seen in Fig. 10 below. We also found that mechanically scoring the shell is a difficult and time consuming task due to the hardness of the outside shell. For this reason, scoring the argan nut shells is only a useful method if a more convenient solution can’t be found.

Fig. 10. A photograph illustrating the ideal scoring pattern of an argan nut. Each score is cut vertically along the nut and in the middle of each full section of shell.

Pressure cooking the dry argan nuts resulted in almost no change from the control set. Pressure cooking soaked argan nuts resulted in an interesting cracking behavior within the shells. The whole batch of nuts tested were covered with clearly identifiable cracks demonstrated in Fig. 11. The presence of these cracks did make the nuts easier to crack with both the squeezing and screw device. Unfortunately, kernel yield was not improved from this method. The squeezing device cracked these nuts as if they were the control group, destroying all the kernels in this test. The screw device, performed as it usually does on the control group as well.

On the other hand, pressure cooking the dry argan nuts resulted in nearly no change from the control set. It appears that the pressure cooker was only able to crack open shells by increasing pressure in the nut due to the heat of the cooker turning water into expanding vapor, the dry set had no water to vaporize so they did not crack open. The kernels that were extracted from all pressure cooking trials (not just the soaked pressure cooked nut trials) were heavily burnt. The high temperatures of the pressure cooker ended up roasting the nuts that were put into it, resulting in roasted kernels (see Figure 12). Overall, we encourage further testing with different methods of creating pressure differentials, perhaps there is a way to burst open the argan nut shell without introducing immense heat.

Fig. 11. A photograph illustrating the cracks in the argan nut shell induced by pressure cooking soaked nuts. All nuts that were subjected to this trial were covered in cracks similar to this.

Fig. 12. A photograph illustrating the burnt argan nut kernel of pressure cooked nuts. This is an extreme example but all kernels of pressure cooked nuts were roasted to some degree. This is an issue because roasted nuts change the properties of the oil they produce.

Additionally, freezing the argan nuts did not provide any useful changes to the cracking properties of the nut shells. Freezing dry argan nuts lead to almost no change. The trials on freezing soaked nuts proved to provide no unique effects on the argan nut cracking process, the resulting nuts from these trials cracked identically to the soaked (and unfrozen) argan nuts.

Cracking the nuts with puncturing devices proved unsuccessful. Using the nails and screws we had on hand did not result in reliably cracked argan nuts, either the shell split apart partly or the puncturing device destroyed the inside of the nut before actually cracking the shell apart. The applied force was too concentrated on one part of the nut, resulting in a single puncture instead of a network of microfractures. The idea of puncturing nuts also runs contrary to our findings for the rest of the successful trials, where kernels are released more reliably when stress is widely distributed to the entire nut shell. Despite needing more force to cause failure stress on a larger surface area, stress needs to be applied to a larger area in order to allow the shell to fully crack open.

Based on our findings, we recommend that Kibbutz Ketura continues to work with investigating argan nut preprocessing techniques. Soaking and boiling the argan nuts proved to be our most promising experiments. Introducing a soaking or boiling preprocessing method to the current argan nut cracking process at Kibbutz Ketura would help improve kernel yield of argan nuts. Furthermore, we highly encourage the investigation of automating the argan nut scoring process, as the results are promising but the manual labor requirement is far too great for commercial application. Finally, creating weak points within the argan shell using pressure differentials should be further investigated.

CONCLUSION

We investigated preprocessing methods that can enhance the current argan nut cracking process to increase kernel yield. We experimented with soaking, boiling, pressure cooking, puncturing and scoring argan nuts to study their effects. Our results demonstrated that creating weak points in the argan nut shell before cracking will improve overall kernel yield and neater shell fragments. Therefore, we recommend further investigation into similar preprocessing methods for the Kibbutz to find preprocessing methods that work well for their operation.

Soaking and boiling methods did increase the kernel yield, but did not significantly change the force required to crack the nut. The heat exerted on the nuts from the boiling did not show any benefit except for reducing the time needed for the nut to become waterlogged. The water absorbed by the nut in both the boiling and the soaking trials changed the mechanical properties of the nut shell, in turn changing the fracture behavior and increased kernel yield. Furthermore, soaking argan nuts prior to pressure cooking them created large fractures in the shell that significantly reduced the force required to crack the nut. Unfortunately, the kernels inside were burnt and brittle. Given the promising results obtained from the soaked pressure cooked nuts, further experimentation with pressure chambers that do not produce heat is recommended. Finally, scoring the nuts three times parallel to the seam While scoring provides the best results it also is complicated to implement.

Our research demonstrates how weakening the argan nut shell can improve the kernel yield and reduce cracking stress needed to process argan nuts. Furthermore, our findings demonstrate that soaking and boiling trials performed well to increase kernel yield while using the squeezing device. Kibbutz Ketura can implement a similar soaking or boiling strategy to their argan nut cracking process to improve their kernel yield. Importantly, by researching and implementing microfracture enabling preprocessing methods, the Kibbutz could avoid replacing their existing two plate device by alleviating the large nut problem. By exploring the avenues our project highlighted, it may be possible for Kibbutz Ketura to establish profitable argan nut farming allowing them to diversify their agricultural based economy.

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