Nut Sorting (NutS)

Improving and Automating the Manual Argan Nut Sorting Process

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Improving and Automating the Manual Argan Nut Sorting Process

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ABSTRACT

Kibbutz Ketura uses a manual crate sifting system to sort argan nuts into four groups by size before the cracking process. This is necessary as the cracking machine struggles with large size variance and nuts with multiple kernels. Our project was to design and build a proof-of-concept sorting machine to aid in scaling up production. The resulting machine was 290% faster while maintaining accuracy comparable to the sifting crates. The size groups Ketura uses were condensed into three size groups. As Kibbutz Ketura and partner Kibbutzim start to expand argan agriculture, scalability is needed.

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1.0 INTRODUCTION

Argan trees are a wild and tropical species of trees that are endemic to the south-western region of Morocco. These trees produce nuts that contain a rare oil used primarily in the cosmetic industry. The argan oil market size is estimated at approximately $86.5 billion in 2021 and has an expected market value of $426 billion by 2030 (Polarois Market Research., 2022).

Kibbutz Ketura is a kibbutz located in the Arava region of the Negev desert that has been attempting to domesticate the argan tree for oil production. At Ketura, they use a multistep process as shown in Figure 1.1 to take the argan fruit and produce argan oil. They use a potato peeler to remove the nut from the fruit and sort the nuts by size using a series of crates with different sized holes. The sorted nuts are cracked using a cracking machine giving a mix of cracked shells and loose kernels that are sorted by another series of crates and a saltwater bath in which the kernels float. The kernels are pressed for oil which is put in a jar to sit for two to three weeks while the sediment in the oil sinks to the bottom leaving pure argan oil at the top.

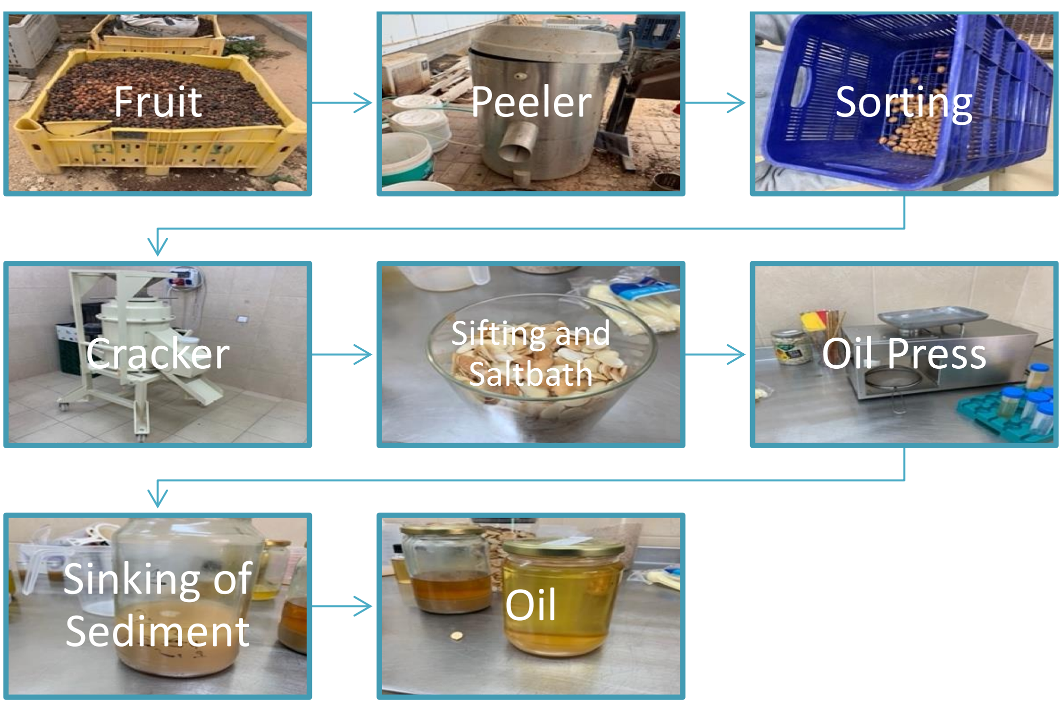

Figure 1.1: Kibbutz Ketura's Argan Oil Process

Our project addresses the sorting stage of the production process. The method of using crates to sort the nuts is very time and manpower intensive creating a bottleneck in the entire process. When Kibbutz Ketura scales up their argan oil production, this method would be unfeasible.

The goal of this project is to create a proof-of-concept machine that improves on Kibbutz Ketura's manual argan nut sorting process through automation. The objectives of this project are:

1. **To create a proof-of-concept for an automatic and continuous argan nut sorting machine that requires minimal human input.** Kibbutz Ketura wants a machine where they can "press a button and walk away"; one that requires no active participation in its functioning. In being continuous, the machine should not require someone to continually move the nuts from one section of the machine to the next. Instead, the machine should only have to be loaded with nuts and have the sorted nuts removed.

2. **To improve upon the nut size groups to increase the efficiency of the argan sorting process.** Currently, Ketura uses a system of crates with a modified grid-like structure at the bottom of the crates that allow nuts of the rough size groups to fall through. The current nut groups are in part determined by the already in-place crate structure. With a new more precise sorting machine there is an opportunity to re-establish the size groups to be more efficient and create less waste.

3. **To learn more about the potential role argan oil has within kibbutz agriculture and the future of the local argan industry.** Our sponsor has goals to scale-up and expand argan within the region. There is potential through automation and agricultural development for large benefit and profit for the local communities.

2.0 BACKROUND

2.1 Negev Desert

Ketura is an agriculture-oriented kibbutz in the Negev Desert approximately 47km north of central Eilat. This area is known as a hyper-arid region. Hyper-aridity is defined to be a condition where the supply of water is extremely scarce and difficult to meet the population and agricultural demand (Hillel et al., 1997). The region has extreme climate conditions with the hottest month having an average temperature of 28.6°C and the coldest month having an average temperature of 11.3°C. Furthermore, the region's wettest month only receives 13mm of rainfall and most of the summer months do not receive any rainfall. In 2021, the area had only 8 rainy days (Yotvata Climate: Temperature Yotvata & Weather By Month - Climate-Data.Org, n.d.). The extreme climate conditions of the Negev Desert have led to a unique agriculture portfolio for communities such as the kibbutzim in the region.

In one study, "Ancient Desert Agriculture of the Negev", the authors claim that in regions receiving less than 150 mm of rainfall annually, the only probable way of an agriculture portfolio is through depressions or water runoffs (Evenari et al., 1961). These harsh conditions led to crops like dates being grown as they do not require direct rain-fed irrigation like most fruits and vegetables. However, a date tree's water demand still ranges from 500 to 1000 liters per day, depending on the time of year (N. Solowey, personal communication, 2023). While in recent years Israel has made significant advancements in water conservation, they still face the risk of water depletion from a major water source, underground aquifers, due to over pumping (GroundWater, n.d.). Consequently, regions in the Negev Desert – like Ketura – will not have this dependable source of water in thirty to fifty years (N. Solowey, personal communication, 2023). This has led communities to look for other crops that will use less water and still be profitable.

2.2 The Argan Plant

Kibbutz Ketura has been interested in argan trees since the 1980s when Dr. Elaine Solowey introduced them to the region. These trees are suited to the local environment of scorching hot summers and brackish water (A. Nerd et al., 1993). Additionally, argan trees require at most eighty liters of water per day, considerably less than date trees for growth (N. Solowey, personal communication, 2023). Furthermore, argan trees are best grown in dry to medium moisture and can effectively withstand drought and heat (Argania Spinosa - Plant Finder, n.d.).

Since argan trees can be grown in the Negev, Kibbutz Ketura is working to make argan oil a commercially viable export of the region. There are further benefits to growing argan in the region such as the flexibility of harvesting and extracting oil from the nuts. Argan fruits can be stored for years and still have their oil extracted with insignificant decrease in quality (N. Solowey, personal communication, 2023). This means that Ketura can focus on date farming, which is time sensitive, and turn their efforts to argan oil when it is convenient. There is also already an established market for argan oil which sells for around $300 per liter (N. Solowey, personal communication, 2023).

2.3 Sorting

Currently, Kibbutz Ketura faces problems in removing the kernels from the argan nuts since some argan nuts have multiple kernels inside of them and there is a wide variety of nut sizes. Nuts with multiple kernels are more difficult to crack using the current cracking machine and are often left only partially cracked. The chance a nut has multiple kernels increases with the size of the argan nut. The cracking machine also does not work well when there is large variance in nut sizes put in at the same time (N. Solowey, personal communication, 2023).

Consequently, Ketura grouped the nuts into four distinct group sizes based on the small diameter of the nuts before cracking. As shown in Figure 2.1 these are: less than or equal to 1.20cm (Small), 1.21cm - 1.50cm (Medium-Small), 1.51cm - 1.70cm (Medium-Large) and greater than 1.70cm (Large).

Figure 2.1: Ketura's Argan Nut Size Groups

From top to bottom the size groups are Small, Medium-Small, Medium-Large, and Large.

The Small and Medium-Small groups are favored as they represent 90% of the total distribution. While the Medium-Large group is acceptable, the Large group is rejected from the cracking process (N. Solowey, personal communication, 2023).

To sort the argan nuts Ketura uses a system of modified crates which are pictured below in Figure 2.2.

Figure 2.2: Sorting Crates Used at Kibbutz Ketura

The series of crates have different sized holes that were either cut-in or part of the crate. To sort the nuts, they manually shake the crate to sift through the nuts. This process is repeated for each sized crate and in total takes thirty to forty minutes for 10kg of nuts. Problems with this method include nuts getting stuck in the holes and nuts clumping together because of the thin layer of sticky residue left behind by the peeling process (N. Solowey, personal communication, 2023). Both these problems must be resolved manually.

2.4 Potential Automated Sorting Methods

A potential sorting method needs to fit the scale of Ketura's operation of 1-3 metric tons/year while being simple in design, low cost, and requiring little human interaction. There are several methods with the potential for automation that are relevant for this scale of operation.

2.4.1 Vibrational Analysis

This sorting method, pictured in Figure 2.3, involves separating nuts based on size using vibration from the collision of nuts against a steel plate. The mass of the nut is determined with an accelerometer which measures the frequency of collisions on the steel plate. Using the calculated mass to infer size, an airbrush is used to sort the nuts into their proper size groups.

One study used this method to separate pistachio nuts (R. Haff & T. Pearson, 2007). The accuracy of this method ranged from 89% to 99% based on how many nuts were put in the system per second. However, this method is expensive as the equipment costs approximately $2000 USD, which is significantly higher than our budget (R. Haff & T. Pearson, 2007). Additionally, given the objective to sort argan nuts based on their small diameter, work would need to be done to adjust this method.

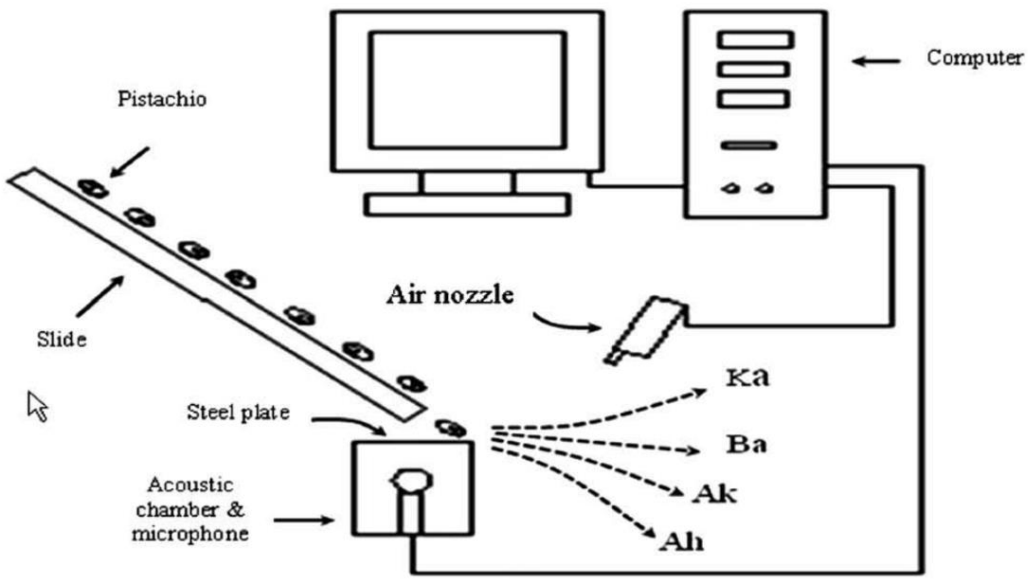

Fig. 2. Schematic of pistachio classifier based on acoustic emissions.

Figure 2.3: Vibration Analysis Sorting Machine Schematic (R. Haff & T. Pearson, 2007)

2.4.2 Drum Sorting Method

This sorting method involves placing an openwork sorting drum with holes against a feeder system over a collection mechanism that sorts based on size. The drum used for sorting is at a downward angle from the feeder system, has holes that increase in size as they get further away from the feeder, and rotates to keep the objects moving and falling out at the appropriate places (Piekaj, 2019). This method is well suited for objects of small diameters, which applies to argan nuts that typically range from 0.8cm to 2.2cm. Figure 2.4 shows an example of a drum sorter and indicates the direction of motion. However, this method was not feasible because the sorting process would take a long time to complete (Piekaj, 2019). Additionally, it would be difficult to source the parts for a drum sorter locally. The difficulty of construction and the time required to complete the process made this method less desirable to the goals of the project.

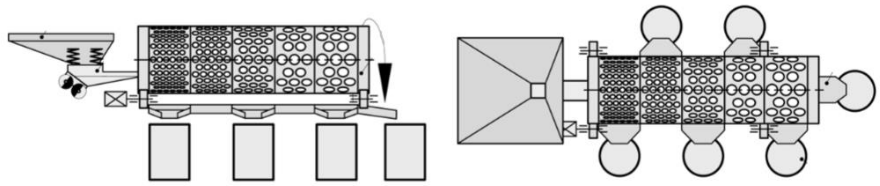

Figure 2.4: Drum Sorting Machine (Piekaj, 2019)

2.4.3 Roller Sorter Method

The roller method consists of using two cylindrical rollers to sort based on the diameter of objects. This method would involve a feeder system that releases objects onto the rollers placed at a downward angle. The motorized rollers turn inward towards each other to move objects along them. The rollers are angled slightly away from each other to sort the objects based on their diameter in increasing order. Although drum sorting is better at sorting smaller diameter objects, this method would be especially useful due to its low cost and simple construction as well as being useful in sorting out a wide range of sizes (Piekaj, 2019). Figure 2.5 shows an example of a roller design used for grinding balls.

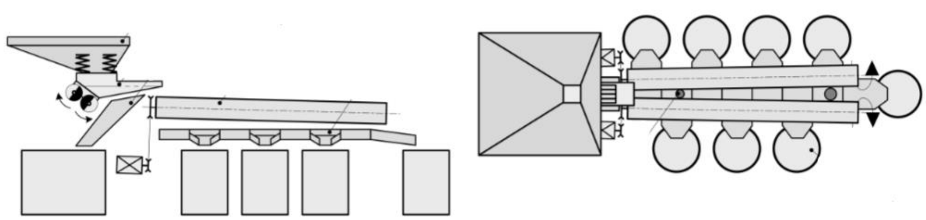

Figure 2.5: Roller Sorting Machine (Piekaj, 2019)

3.0 AUTOMATED ARGAN NUT SORTING MACHINE

This section covers the completion of objective one: to create a proof-of-concept argan nut sorting machine for an automatic and continuous machine. It goes over the requirements of the sorting machine and the resources it was built with as well as the final product.

3.1 Requirements and Resources

The sorting machine had performance requirements and design requirements. For performance requirements, the machine needed to sort 10kg of nuts at least as fast as the manual crate sifting method, around 40 minutes. It also needed to be able to sort the nuts into at least 3 groups. One design requirement was that the machine needed to be shown to be feasibly made autonomous and to run continuously so we can evaluate the implications our proof-of-concept can have on the scaling up of the oil production process at Ketura. The other design requirement was that it needed to be built through locally sourced parts and tools.

The primary tools we used consisted of hand tools such as: saws, a hammer, a screwdriver, a measuring tape, and drills. Any additional tools were acquired from the local machine shop in Ketura. Most construction materials, the plastic drum of the feeder and all wood frame pieces were sourced locally from scrapyards. Screws, nails, rollers, motors, and internal parts of the feeder designed for controlling clogs and feed rate were sourced from various hardware stores in the city of Eilat.

3.2 Product

The final prototype as shown in Figure 3.1 consists of 2 main parts, the rollers and the feeder. The rollers are the mechanism that sorts argan nuts and the feeder releases nuts at a controlled rate. The feeder stands at 148cm tall and is 100cm by 56cm in length and width respectively and the sorter stands at 55cm by 118cm by 63.5cm (height, length, width). The crates that nuts are collected in for each size group can be removed from the assembly to easily move onto the cracking process in oil extraction.

Figure 3.1: Sorting Machine

3.2.1 Rollers

The roller mechanism has two aluminum rods attached to motors with 87cm of space available for the nuts to roll down. The rollers are secured in place by a bearing and a motor shaft on opposite sides. They are angled downward by 2.43°. The motors spin the rollers inward which allow the nuts to move more freely down the length of the rollers. The bearings help the rollers spin more freely. From the end that argan nuts are fed onto the rollers, the gap starts at 0.25cm and expands to 2.5 cm by the other end giving an angular separation of 1.48°. This entire roller-motor-bearing system is secured by a wooden frame. Wooden guards are immediately above and along either side of the rollers to prevent nuts from falling off the assembly due to bouncing or backup. Figure 3.2 shows the completed roller system and includes the slight downward angle the rollers are placed at. Figure 3.3 is a SOLIDWORKS model of the roller system that does not include the guard rails to provide a more detailed view of the rollers and the motors.

Figure 3.2: Image of the Completed Roller System

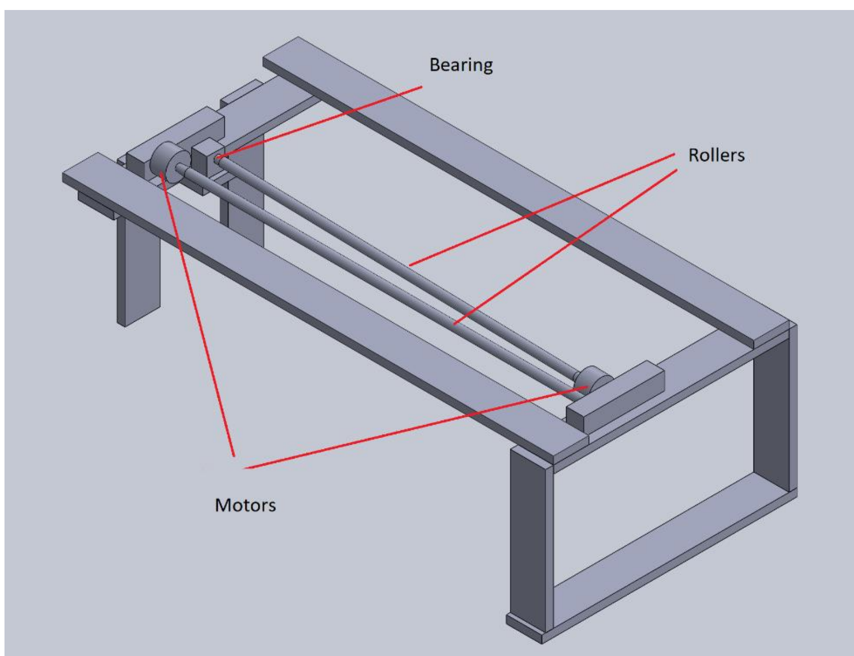

Figure 3.3: CAD Model of the Roller System with no Guardrails

3.2.2 Feeder System

The feeder mechanism is a 208-Liter (55 gal) plastic drum cut in half, with a 6cm x 9cm opening at the bottom. This drum acts as a hopper that utilizes a gravity assisted ramp to transfer the nuts onto the rollers. Figure 4.4 shows the feeder system and Figure 4.5 shows the SOLIDWORKS model of the feeder system.

Figure 3.4: Image of Feeder

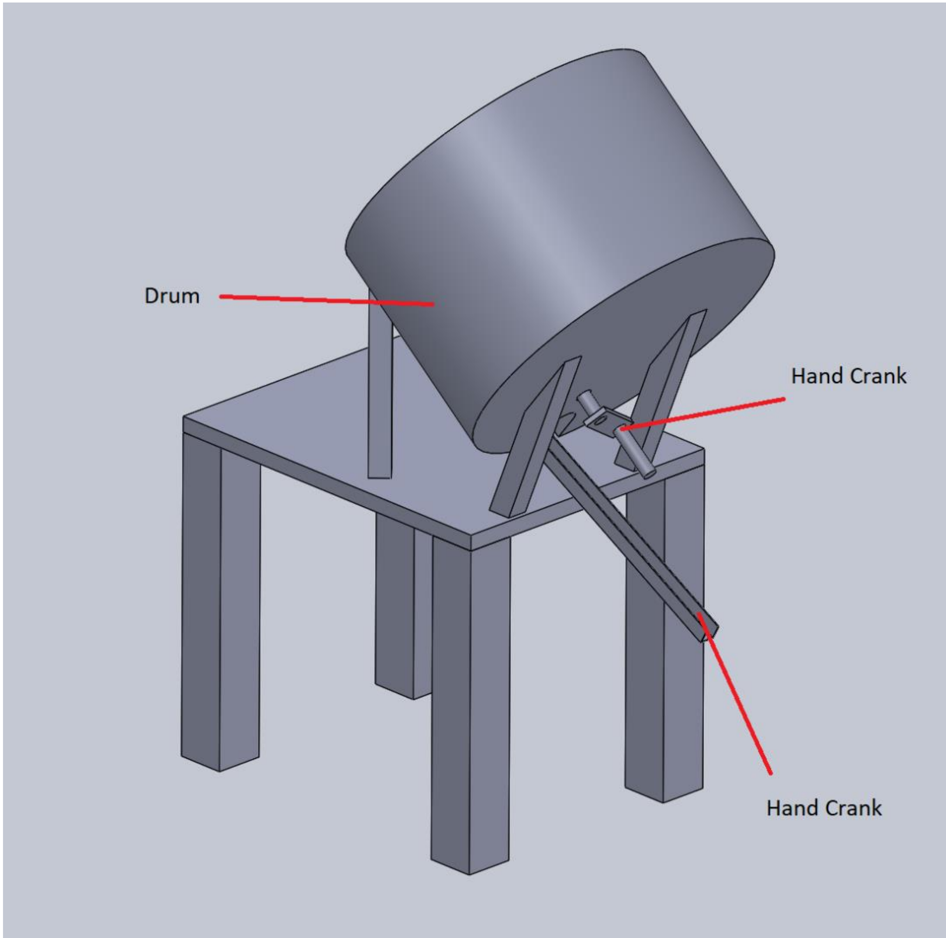

Figure 3.5: CAD Model of Hopper Design

A rotating plate, attached to a hand crank to allow for manual rotation, keeps the nuts moving within the hopper and regulates the flow of nuts from the feeder to the rollers. The design is implemented so the wheel blocks the entrance of the opening except for an elevated section. This limits the time that nuts are allowed to pass through and allows for the flow rate to be controlled by the speed of rotation, as seen in Figure 3.6. Additionally, extra wooden and plastic parts, each with holes in them to fit around the crankshaft, were fixed to either side of the hopper to ensure steady rotation of the plate with no wobbling.

Figure 3.6: Image of the Rotating Plate in the Feeder System

A hand crank was chosen in place of a motor due to local supply limits and the inability to source either gearing or a proper motor to ensure appropriate torque. While not automatic, the design gives the ability to automate easily in the future with proper resources.

4.0 EVALUATION

Performance of the sorting machine was evaluated by running experiments on the functionality, sorting consistency, sorting accuracy, and sorting speed. These experiments were run on both our machine and using the manual crate sifting system to provide a baseline for comparison.

4.1 Technical Feasibility

Due to the limitations in resources and time the sorting machine was not automated. Instead, the feeder mechanism was implemented using a hand-crank in-place of a motor. We test the feasibility of automation in this experiment.

4.1.1 Method

The technical feasibility of the machine was evaluated by feeding 6kg of nuts into the machine and running the feeder and rollers together to determine if any failures occurred during the sorting process. While sorting, any problems and failures were recorded when they occurred. We derived possible errors from problems with previous machine iterations. The full methodology is in Appendix A.

4.1.2 Results

Shown in Table 4.1 are the problems and the times they occurred while sorting 6kg of nuts. The only problem in the functionality test was the loss of nuts through either on the ramp, or as they entered the rollers. The full data points in Appendix A.

Table 4.1: Results of Functionality Experiment

Errors	*Occurrences*
Roller falling off	0
Rollers stopping	0
Spilling	30
Hand crank jam	0
nuts falling off	1
remaining nuts	2
Total	33

4.1.3 Discussion

The only problem that occurred was the loss of nuts as they left the feeder to the ramp (spilling) or on the transition from the ramp to the rollers (nuts falling off). This was either due to too many nuts being released causing the nuts to go over the ramp walls, the nuts bouncing against the frame, or the nuts being small enough to fall through the roller walls. Over the entire trial, less than 50 nuts out of approximately 2600 nuts were lost. This can be easily resolved by either reducing gaps in the roller walls or by picking up the nuts and adding them to the next sorting batch.

4.2 Sorting Consistency and Accuracy

Consistency and accuracy of each sorting method was evaluated in the same experiment.

4.2.1 Method

A control was established for accuracy by hand sorting a batch of 100 nuts with a caliper. The nuts were sorted into the groups originally used by Ketura to provide more consistency to the data. The nuts were re-mixed and sorted by the machine and by the crates. The full methodology for the experiment is in Appendix B. Accuracy was determined by comparing the percentage of nuts that were sorted correctly to the control. For this, Kibbutz Ketura's size groups of less than or equal to 1.20 cm (Small), 1.21cm - 1.50cm (Medium-Small), 1.51cm - 1.70cm (Medium-Large) and greater than 1.70cm (Large) were used. Consistency was measured by running three trials of this process and comparing the standard deviations of the nuts sorted into each size group.

4.2.2 Results

The results for the sorting machine and crates accuracy are visualized in Figure 4.1. Figure 4.2 shows the results of the consistency experiment. The full experiment results are in Appendix B.

As shown in Figure 4.1, the sorting machine had an overall accuracy of 79.74% while the crates had an overall accuracy of 81.67%. The machine was more accurate for the Small and Medium-Large size groups by 30.77% and 22.52% respectively. For the Medium-Small group the machine was only 2.69% less accurate than the crates, but for the Large group the machine was 26.5% less accurate.

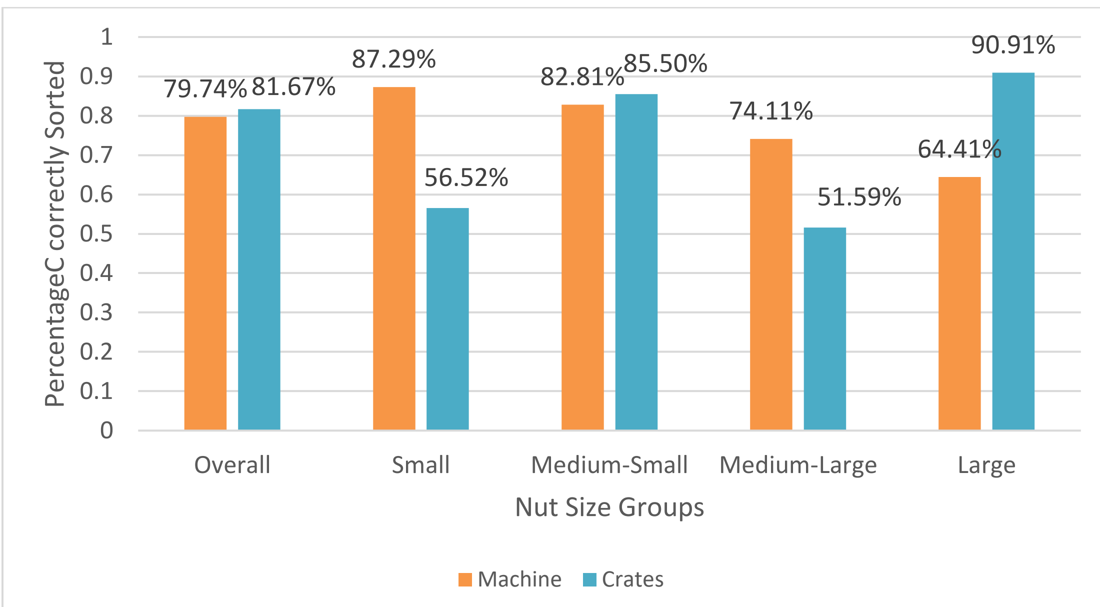

Figure 4.1: Percentage of Nuts Sorted Correctly per Group.

According to Figure 4.2, the sorting machine had a consistency worse than the crates with a mean standard deviation of 1.44 higher than the crates. The machine was less consistent for all the size groups by more than a standard deviation for almost all groups. The consistency was much worse for the Medium-Small and Medium-Large groups. For the Medium-Small group the machine had a standard deviation of 3.21 which was 2.21 higher than the crates. In the Medium-Large group the machine had a standard deviation 1.5 higher than the crates.

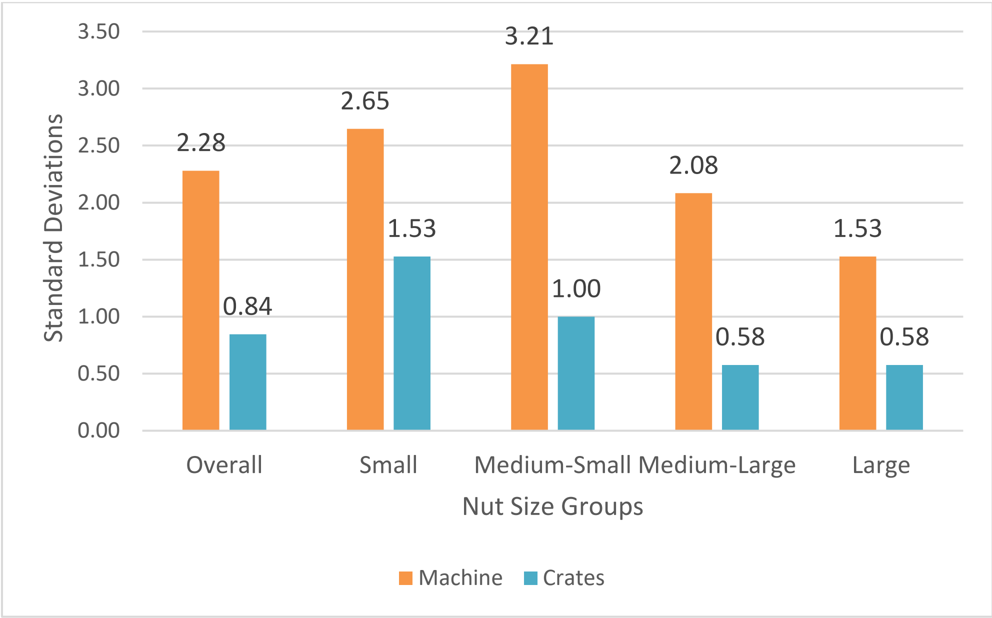

Figure 4.2: Standard Deviations of Nuts Sorted into each Group

The overall represents the mean of the standard deviations for each method.

4.2.3 Discussion

The non-perfect accuracy and consistency in the crates is likely due to the slight variation in hole difference as well as the warping of the crates. This was especially visible in the crate sorting between the Small and the Medium-Small groups. This crate is also where the trials showed the least accuracy and consistency in sorting. Since the crate gaps do not change, it is unsurprising that they are more consistent than the sorting machine.

The inaccuracy of the machine specifically in the larger size groups is likely due to the imperfect bearing fixtures. This is visible in Figure 4.1 as the accuracy decrease and the size groups get larger. The current setup has a gap range of 2.15cm - 2.5cm for the largest gap and a 0.25cm - 0.40cm gap range for the smallest gap. When spinning it is observed the nuts occasionally force the roller gap larger. If the bearings were improved, we expect an increase in both accuracy and consistency.

4.3 Sorting Speed

4.3.1 Method

To determine the speed at which the sorting machine is capable of sorting nuts, we ran three trials each with around 5kg of nuts. 5kg was chosen because it allows for an easy comparison to the current method within a timely manner. A control group was established by taking the mean sorting time of 5kg of nuts by using the sifting crates over three trials.

To see if there was any delay caused by the transfer to the rollers from the feeder, we ran 5kg again but only through the feeder. We compared the results of the feeder rate to the results of the sorting rate. We ran four trials of the feeder rate and compared the results to the sorting rate to see if there were discrepancies between the sorting rate and the feed rate.

Another experiment was run to determine if the weight placed into the hopper would affect the feed rate. We looked to see if it would be better to load the feeder all at once or if it would be better to load it in portions of half the amount used for the test. This was accomplished in the experiments by having two sets of trials; one set would be loaded in portions of one half of the 5kg and the other set would be loaded with the entire 5kg in each trial. The results of the two sets were compared to each other to see if there was any difference in the rate based on the amounts loaded in.

In all trials except for the sorting rate of the crate method, the number of nuts remaining in the feeder was measured to see if the feeder was functioning efficiently. The full methodology and data points are in Appendix C.

4.3.2 Results

The resulting speed differences between the crate sorting method and the machine sorting method are shown in Figure 4.3. The machine sorting method has two data points, one for loading in portions and one for loading all at once. Figure 4.4 shows the comparison between the feed rates and the sorting rates, with a portion loading and full loading point for both rates. Both charts show the difference between portion loading and full loading.

Figure 4.3 shows a comparison between the sorting rates of the machine and the crates. The machine with portions is the fastest, followed by the machine all at once, and then the sifting crates. This chart shows a comparison between the feed rate and sorting rate. The feed rate is faster than the sorting rate and the portion loading is faster than the full loading in all cases.

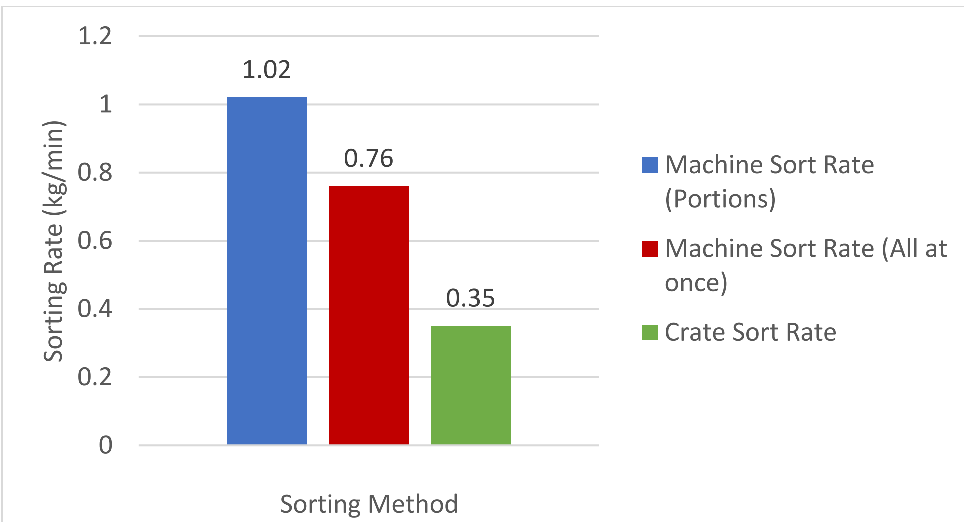

Figure 4.3: Comparison Between Machine and Crate Sorting Speeds

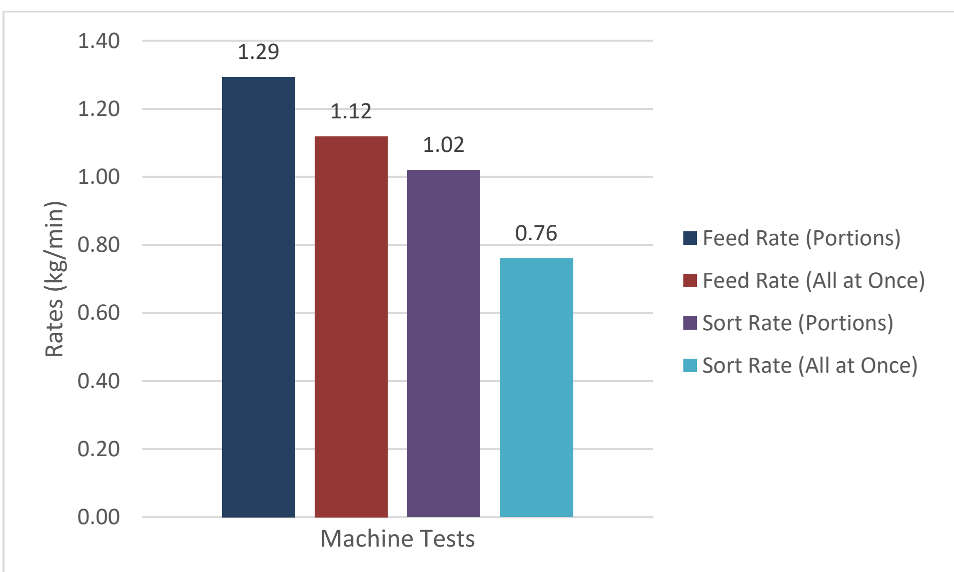

Figure 4.4: Comparison Between the Sorting Rate and the Feed Rate

4.3.3 Discussion

The sorting machine functioned at a mean sorting rate of 1.02kg/min when the nuts were placed in the feeder in portions. When nuts are placed in all at once the sorting rate fell to 0.76kg/min. These are both faster than the rate of Ketura's crate method, which sorts at a mean of 0.35kg/min as seen in Figure 4.3. Converting this to the 10kg batches the Kibbutz Ketura sorts in, it would take 9.80 minutes for the machine (nuts in portions) and 28.47 minutes for the sifting crates to sort. This is a time improvement of 291.43%.

The mean feed rate without the rollers attached was 1.29kg/min when loaded in portions and 1.12kg/min loaded in full. The feeder by itself feeds faster than when combined with the rollers, which have a sorting rate of 1.02kg/min and 0.76kg/min for portion and full loading respectively. The portion loaded feed rate was 26% faster than its sorting counterpart. The fully loaded feeder was 47% faster. These disparities show that there are improvements that can be made to the transfer between the feeder and roller systems in the future, and that the sorting rate can be improved for the machine.

The data from the comparison to the crate sorting method and from the feeder system show that the portion loading has a faster rate than the full loading system. The portion loaded feed rate is 15% faster than the fully loaded feed rate and the portion loaded sorting rate is 34% faster than the fully loaded sorting rate. The difference in these rates can likely be attributed to the feeder and the rotating plate due to the materials that the feeder and rotating plate are constructed from.

In all the trials involving the feeder, it was found that there were nuts left in the feeder. The range of nuts remaining in the feeder was between four nuts (9.2g) and thirteen nuts (29.9g) with the mean being nine nuts(20.7g) left in the sorter. This number is acceptable, as those levels are an insignificant amount of the 5kg trial batch.

5.0 FUTURE WORK

The progression of the sorting machine from a proof-of-concept design to a fully automated system can be feasibly accomplished with more available resources.

5.1 Automation of Feeder

Currently, the feeder system is operated by a hand crank. Adding a high torque motor mounted onto the rotating plate in the argan feeder would reduce the human interaction required for the machine. With other manufactured parts that were not available in the proof-of-concept construction, such as the use of an auger as the internal feeder mechanism instead of a rotating plate or metal guards around the track nuts are fed onto, significant improvements in feed rate, smoothness of internal mechanism rotation, and preventing spillage could be made in a short time frame.

5.2 Improvement of Roller System

To reduce the stoppage errors as well as reduce the rollers as a bottleneck, we recommend increasing the torque applied to the rollers. This can either be accomplished through gearing or sourcing motors with higher torque. We also recommend a properly sized and spaced bearing system as well as longer rollers to improve the accuracy and consistency in the sorting.

5.3 Scale-Up Production

To scale up production once the machine is fully automated we recommend multiple sorting machines running side by side with one operator overseeing all of them, making upscaling take less manpower. This will overcome the primary problem of upscaling in the Negev.

6.0 MODIFYING SIZE GROUPS

This section describes the method, results, and discussion for compartmentalizing the size groups the nuts are sorted into. The procedure involved calculating a chi squared value to test for statistical significance and modifying the groups accordingly.

6.1 Methodology

A chi squared test is a statistical hypothesis test used to compare observed results with expected results. The purpose of it is to determine if the relationship between these results is by coincidence or by relationship. Our chi squared test involved using the crate system to identify which groups would most likely need size group modification. The test was run for three trials: all the groups, the Medium-Small group, and the Medium-Large group. The Medium-Small and Medium-Large groups were selected as they had the most uncertainty in the number of kernels per nut. These size groups were divided into two more categories. Specifically, Medium-Small was divided into Medium-SS (small-small) and Medium-SL (small-large) with size ranges of 1.2cm – 1.35cm and 1.35cm – 1.5cm respectively and the Medium-Large group was divided into groups Medium-LS (large-small) and Medium-LL (large-large) into size ranges of 1.5cm – 1.6cm and 1.6cm – 1.7cm respectively.

Since the experiment analyzed the correlation between the size of a nut and the number of kernels in the nut, our research hypothesis was "There is a relationship between the size of the nuts and the number of kernels present in the nuts". We simultaneously tested the null hypothesis, "There is no relationship between the size of nuts and the number of kernels present in the nut."

A caliper was used to measure the size of the nuts and a vice grip to crack and record the number of kernels in the nut. The recorded data was used to find the chi squared value through the procedure of the chi squared test detailed in Appendix D.1. This test comprised of computing a chi squared value which was done by comparing the joint distribution and expected frequency data points. A test value was also found by identifying an appropriate alpha level and degrees of freedom to compare the chi squared value to. This allowed us to test for any statistical significance in our research hypothesis for all three trials.

6.2 Results

Each data point in Table 6.1 and Table 6.2 were compared to each other using chi squared calculations, referenced as x and y respectively in Table 6.3 below.

Table 6.1: Joint Distribution for All Size Groups

This table shows the relationship between size of the nut and number of kernels in the nut.

MORE THAN 1 KERNEL	SMALL	MEDIUM-SMALL	MEDIUM-LARGE	LARGE	TOTAL
YES	0	18	37	10	94
NO	77	142	16	0	206
TOTAL	77	160	53	10	**300**

Table 6.2: Expected Frequency Table for All Size Groups

This table shows the expected frequency if there was no relationship between the size of the nut and the number of kernels in the nut.

MORE THAN 1 KERNEL	SMALL	MEDIUM-SMALL	MEDIUM-LARGE	LARGE	TOTAL
YES	16.68	34.67	11.48	2.17	65.00
NO	60.32	125.33	41.52	7.83	235.00
TOTAL	77.00	160.00	53.00	10.00	**300.00**

Table 6.3: Chi Squared Calculations for All Size Groups

This table shows the chi squared value for all the values to be 21.00

$x - y$	$(x - y)^2$	$(x - y)^2/x$	**Result**
-16.68	278.33	0.00	0.00
16.68	278.33	3.61	3.61
-16.67	277.78	15.43	15.43
16.67	277.78	1.96	1.96
25.52	651.10	17.60	17.60
-25.52	651.10	40.69	40.69
7.83	61.36	6.14	6.14
-7.83	61.36	0.00	0.00
Total			**21.00**

The total value seen in Table 6.3 represents the chi squared value.

To compute the test value, the alpha level was determined to be $\boldsymbol{p} = \mathbf{0.025}$ since the sample size was $\boldsymbol{n} = \mathbf{300}$, as seen in Table 6.1.

The degrees of freedom depend on the columns and rows of the joint distribution table and is calculated by:

$df = (n - 1) * (m - 1)$; where n is number of columns and m is number of rows.

For Table 5.1 where $n = 2$ and $m = 4$, the $df = 3$.

As illustrated in the normal distribution chart in Appendix E, with an alpha level $p = 0.025$ and $df = 3$, the test value is approximately 3.18. Furthermore, as seen in Table 6.3, the chi square value is 21.00. The chi squared value is larger than our test value.

By using the chi squared test for the Medium-Small and Medium-Large group, the results show the chi squared value to be larger than the test value for all trials. Subsequently, there is statistical significance for all tests.

Table 6.4: Joint Distribution Table for Medium-Small Group

This table shows there to be 2 columns and 2 rows of data to calculate df = 1

More than 1 Kernel?	Medium-SS	Medium- SL	Total
Yes	14	22	36
No	83	28	111
Total	97	50	147

As the alpha value remains the same and the number of columns and rows change, as seen in Table 6.4, the alpha value $p = 0.025$ and $df = 1$.

Table 6.5: Chi Squared Calculations for Medium-Small Group

This table shows the chi square value for the Medium-Small group to be 52.23

$x - y$	$(x - y)^2$	$(x - y)^2/x$	Result
-9.36	87.66	43.83	43.83
9.36	87.66	0.89	0.89
9.36	87.66	5.48	5.48
-9.36	87.66	2.04	2.04
Total			**52.23**

Utilizing the normal distribution chart in Appendix E with an alpha level $p = 0.025$ and $df = 1$, the test value is approximately 12.7. Additionally, as seen in Table 6.5, the chi square value is 52.23; signifying that the chi squared value is larger than the test value.

Table 6.6: Chi Squared Calculations for Medium-Large Group

This table shows the chi squared value for the Medium-Large group to be 4.79

$x - y$	$(x - y)^2$	$(x - y)^2/x$	Result
-3.04	9.23	0.46	0.46
3.04	9.23	0.71	0.71
3.04	9.23	0.54	0.54
-3.04	9.23	3.08	3.08
Total			**4.79**

With $p = 0.1$, and $df = 1$ for the Medium-Large group, the test value becomes 3.1. As the chi squared value is 4.79, referenced in Table 6.6, the chi squared value is larger than the test value.

6.3 Discussion

When evaluating the chi squared test results for all the size groups, we can see there is statistical significance since the chi squared value is larger than our test value with a margin of error of 2.5%. This means that there is strong evidence to our research hypothesis, "There is a relationship between size of nuts and number of kernels in a nut."

By proving this, we have reason to analyze specific categories in more detail, specifically: Medium-Small and Medium-Large, as they have the highest variation in number of kernels, as seen in Figure 6.1. Utilizing the chi squared test, the results show that there is statistical significance in our research hypothesis for both groups. Consequently, we can make both groups more accurate for cracking by dividing them into Medium-SS and Medium-SL and Medium-LS and Medium-LL

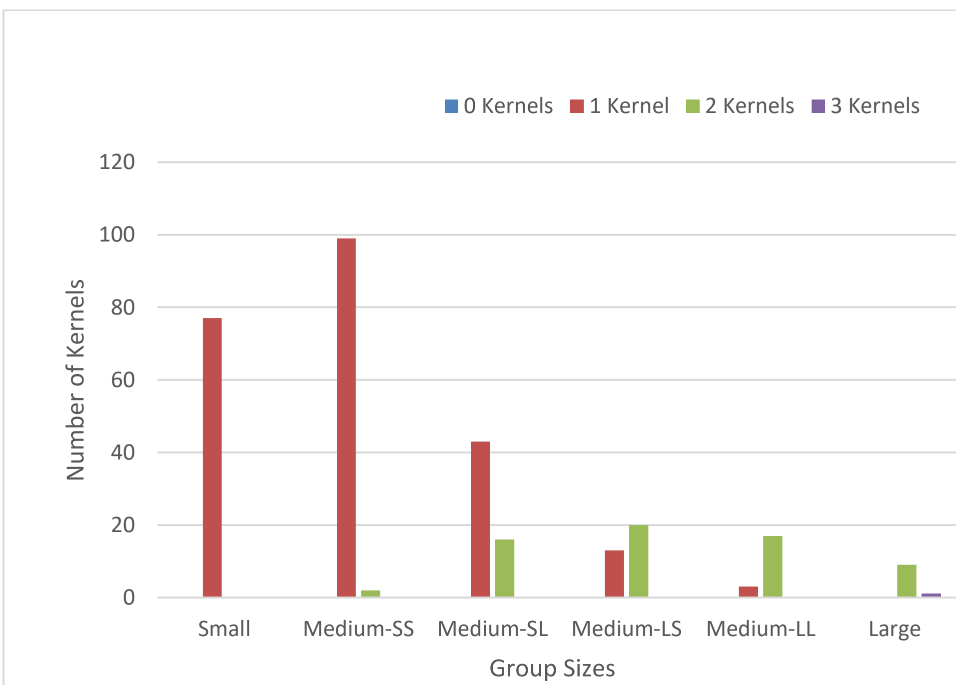

Figure 6.1: Distribution of Kernels by Groups Sizes

In Figure 6.1, groups Small and Medium-SS have very similar distributions of kernels. For example, all kernels in the Small group and 97% of the Medium-SS group have one kernel. As the Small and Medium-SS group have minor variations in kernels per nut, they can be combined into one group. When Medium-SL and Medium-LS are compared, they have similar distributions for more than one kernel. Subsequently, these groups can also be combined. Lastly, Medium-LL and Large can also be combined into a singular group as Medium-Large only has 3 nuts with one kernel and Large has exclusively more than one kernel. In summary, our recommended groups are: 0 - 1.35 cm (Small), 1.36 – 1.60cm (Medium), 1.61cm and larger (Large).

6.4 Cracking Efficiency Test

6.4.1 Method

To analyze the effectiveness of the new sorting groups. A sample of nuts was measured using a caliper and divided into the three modified groups. These groups were then individually cracked in the cracking machine to test how many nuts partially cracked i.e., did not crack efficiently.

6.4.2 Results

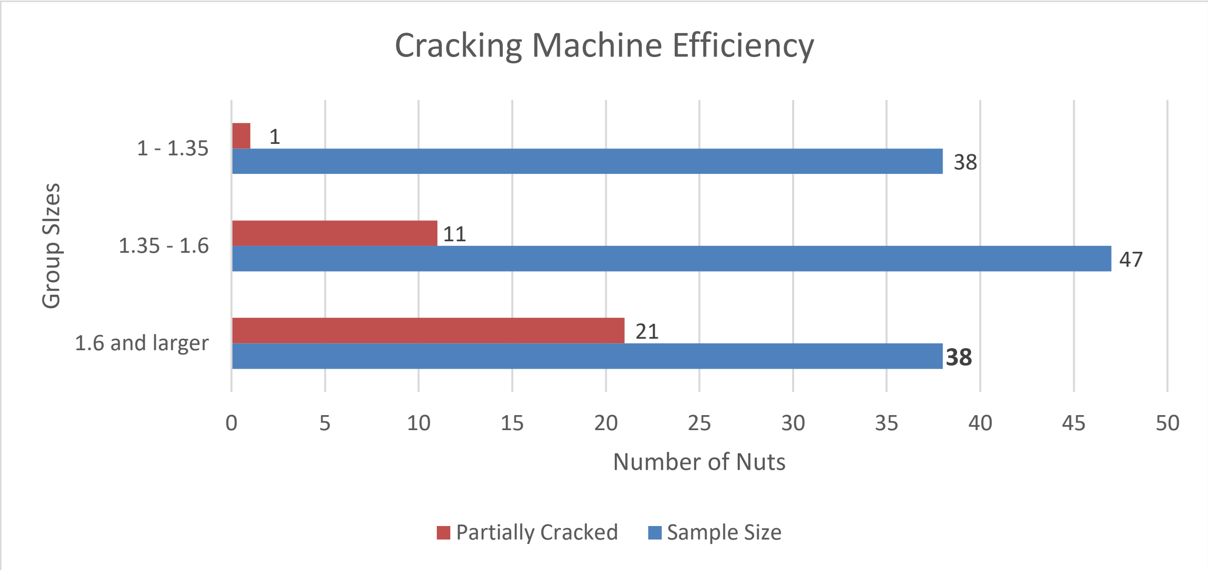

Figure 6.2: Distribution of Nuts Partially Cracked from Sample of Group Sizes

As seen in Figure 6.2, the small group only had 1 nut partially cracked which means 97% of the nuts were efficiently cracked. The Medium category had approximately 77% nuts crack fully while the Large group had less than half the nuts fully crack.

6.4.3 Discussion

The result from the cracking experiment shows that merging Small and Medium-SL – the previous groups – into one group only led to 2% of nuts not being cracked efficiently. Combining these groups lead to more nuts being put in the cracking machine simultaneously. Subsequently, with a negligible percent of nuts cracked inefficiently, a higher yield of nuts can be fully cracked. A limitation of this experiment was that the sample size for each group size was decreased as the cracking machine stops cracking when there are too few nuts left in the machine. As illustrated below in Table 6.7, the Uncracked column represents the number of nuts left in the machine at which the machine stopped cracking. Consequently, the sample size decreased for all group sizes. For this reason, this experiment can be improved by significantly increasing the sample size to get more accurate data.

Table 6.7: Distribution of Nuts Fully Cracked, Partially Cracked and Uncracked for Different Group Sizes

Sizes	Sample Size	Fully Cracked	Partially Cracked	Uncracked
1 - 1.35	50	37	1	12
1.35 - 1.6	70	36	11	23
1.6 and larger	70	26	21	24

7.0 REGIONAL IMPACT OF ARGAN

In this section we discuss the primary benefits of developing argan agriculture in Kibbutz Ketura and the benefit our sorting machine can provide for the future of this venture in Ketura and the Negev desert.

7.1 Development of Argan Agriculture

As mentioned in Section 2, the argan nut has characteristics which prove it to be a successful crop to grow in Israel. Specifically, water consumption has proven to be a major factor in expanding the argan agriculture in Ketura considering that the main crop, dates, requires ten times as much water as an Argan tree (N. Solowey, personal communication, 2023). This is a significant detail as Israel searches for water conservation alternatives due to the extreme water stress it currently faces. With the desert covering 60% of the region, and 50% of freshwater used exclusively for agriculture, there are concerns about depending on water-dense crops such as dates (Israel's Sustainable Water Management Plans, n.d.).

The cultivation and oil extraction process of the argan plant is less time constraining than most crops. Argan nuts can survive at least 6 years after falling off the tree. Furthermore, there isn't a time-constraint in extracting oil after the nuts have been peeled. This is a considerable benefit as most fruits and vegetables require constant attention during growth and cultivation (N. Solowey, personal communication, 2023).

Kibbutz Ketura's goal for argan agriculture is for the trees to be grown alongside their main crop, dates. This system would allow the farmers to focus efforts on the dates, but harvest and process the argan nuts when they have the time. This allows farms to efficiently use their resources throughout the year. Ultimately, Ketura wants to gain the most from their land and labor. Argan shows a unique potential in achieving this in regions where the majority of crops struggle.

7.2 Future of the Argan Industry

At Ketura, argan agriculture is a startup that is invested in finding argan's potential in the region. Success in this venture is important to Ketura's economic stability as the current main crop, dates, incrementally becomes less profitable. For the first time at Ketura, guided tours of the kibbutz made more money than dates (N. Solowey, personal communication, 2023). Consequently, our sponsor has been experimenting with argan nuts as an option for economic diversification.

The current outcome goal of research into argan nuts is the domestication of a few clones that have the necessary oil concentration and nut yield for economic success. (N. Solowey, personal communication, 2023). This had led Ketura to collaborate with neighboring kibbutzim to test specific aspects of argan trees.

Ketura has focused most of their experimentation on finding if the concentration of oil in an argan tree is genetic. Concurrently, a partner kibbutz is testing the cloning of argan trees for further growth. Combined, this research is paving the way for successful argan agriculture. The cooperation among kibbutzim has led to research that would have taken Ketura more than fifty years on their own to take less than half the time (N. Solowey, personal communication, 2023).

Research and experimentation can be a time-consuming process, especially when argan at Ketura is a two-man operation. For Morocco, the biggest supplier of argan oil, they have plentiful cheap labor (*Factory and Manufacturing Average Salaries in Morocco 2023 - The Complete Guide*, n.d.). Most of this labor is manual and time consuming, usually taking up to twenty hours for one liter of argan oil (*Pure Argan Oil - Traditional Production*, n.d.). However, for Ketura, where production of oil and research happen simultaneously, the time constraint is less flexible. Additionally, labor in Israel is significantly more expensive. For example, the labor cost is $1100 USD per month more than Morocco in the manufacturing sector (*Israel Total Wages: Sa: Manufacturing | Economic Indicators | CEIC*, n.d.). This impels Ketura to limit manpower usage while maintaining developments in research and expanding their argan oil production. Ketura would prefer that processes such as peeling, sorting, and separating to be automated and not require active participation. Our proof-of-concept sorting machine can assist in decreasing the total time spent on the oil production operation. This frees up time which can be spent on crucial research.

8.0 CONCLUSION

We have created a proof-of-concept machine that semi-automatically sorts nuts with improved accuracy and speed, but that is less consistent than Kibbutz Ketura's method of crate sifting. We recommend that future work be done to automate the feeding mechanism. Additionally, we recommend increasing torque applied to the rollers to reduce stoppage errors through either gearing or sourced motors as well as customizing rollers. Once done our improved proof-of-concept could be used to scale up argan oil production.

We found that there is a significant increase in nut kernels found in nuts above 1.6cm in diameter. Through this we conclude that adjusting the size groups that Kibbutz Ketura uses to a three-size group system using the sizes 0cm – 1.35cm (Small), 1.36cm – 1.60cm (Medium), and larger than 1.60cm (Large).

Argan oil production is a developing industry in the Negev that shows promise in creating a profitable side crop that would allow local communities more financial security. Automating the process of argan oil production frees up valuable time for further research into advancing argan agriculture in Kibbutz Ketura and the Negev region.

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APPENDIX A: TECHNICAL FEASIBILITY METHODOLOGY AND RESULTS

This appendix details the procedures and results from the technical feasibility experiment. The purpose of this experiment was to test whether the design was technically feasible for operation and automation.

A.1 Procedure

1. Record the mass of nuts that will be sorted through the machine.

2. Identify all functional errors from previous iterations. For instance, spillage, roller stoppage due to clogs, rollers falling off, and hand crank stoppage are recorder.

3. Rotate inner feeder mechanism to its most downward position to not allow any nuts to go through initially, then pour all massed nuts into the hopper.

4. Run a test batch through the machine and operate the machine until the batch is completely sorted.

5. Record all functionality errors that happen during machine operation. Stop machine operation when a negligible number of nuts (around 1-12 left total) remain in the machine.

    a. While testing, operate machine as if the motor strength and sorting speed is ideal. Components of the machine subject to failure are pushed to find the limits of their operation.

A.2 Results

Table A.1: Technical Feasibility Results

Problems from earlier in the machine's development were used as categories. Unidentified problems were added once they occurred.

Errors	*Occurrences*
Roller falling off	0
Rollers stopping	0
Spilling	30
Hand crank jam	0
nuts falling off	1
remaining nuts	2
total	33

APPENDIX B: ACCURACY AND CONSISTENCY METHODOLOGY AND RESULTS

This section evaluates the data and experiment limitations, outlines the procedures for the accuracy and consistency experiment and presents the data points collected.

B.1 Procedures

B.1.1 Hand Sorting

1. Take 100 nuts of random distribution.
2. Using a caliper, measure the nuts and mark on the nuts their smallest diameter.
    a. Most nuts are not circular, but in this case rotate the nuts and record the smallest diameter.
3. Sort the nuts twice.
    a. Once with the categories that the crates sort into and once with the categories we determined would improve cracking efficiency.

B.1.2 Crate Sorting

1. Going largest holed crate to the smallest holed crate sift the nuts.
    a. Shake the crate for 15sec or until 7-10sec after the last nut falls through.
2. Record the nuts per category and the nuts that were sorted incorrectly.

B.1.3 Machine Sorting

1. Randomly drop the nuts one by one down the sorter one at a time.
2. Record which category the nut sorts into and whether it was correctly sorted.

B.2 Data Points

Table B.1: Trial Results for the Accuracy and Consistency Experiment

Machine Trial 1			
Group (cm)	#Nuts Sorted Into	Nuts of Category Sorted Wrong	%Nuts wrong
0 - 1.20	26	5	0.217391
1.21 - 1.50	53	8	0.148148
1.51 - 1.70	11	5	0.416667
1.71<	10	3	0.272727
Total	100	21	
Machine Trial 2			
Group (cm)	#Nuts Sorted Into	Nuts of Category Sorted Wrong	% Nuts wrong
0 - 1.20	30	5	0.217391
1.21 - 1.50	47	10	0.185185
1.51 - 1.70	15	2	0.166667
1.71<	8	5	0.454545
Total	100	22	
Machine Trial 3			
Group (cm)	#Nuts Sorted Into	Nuts of Category Sorted Wrong	% Nuts wrong
0 - 1.20	31	1	0.043478
1.21 - 1.50	48	10	0.185185
1.51 - 1.70	14	3	0.25
1.71<	7	4	0.363636
Total	100	18	

Crate Trial 1			
Group (cm)	#Nuts Sorted Into	Nuts of Category Sorted Wrong	% Nuts wrong
0 - 1.20	33	10	0.434783
1.21 - 1.50	47	4	0.074074
1.51 - 1.70	5	4	0.333333
1.71<	15	0	0
Total	100	18	
Crate Trial 2			
Group (cm)	#Nuts Sorted Into	Nuts of Category Sorted Wrong	% Nuts wrong
0 - 1.20	34	0	0
1.21 - 1.50	46	10	0.185185
1.51 - 1.70	6	7	0.583333
1.71<	14	1	0.090909
Total	100	18	
Crate Trial 3			
Group (cm)	#Nuts Sorted Into	Nuts of Category Sorted Wrong	% Nuts wrong
0 - 1.20	36		0
1.21 - 1.50	45	12	0.222222
1.51 - 1.70	5	7	0.583333
1.71<	14		0
Total	100	19	

Table B.2: Results for the Accuracy and Consistency Experiment.

ACCURACY	OVERALL	0CM - 1.20CM	1.21CM - 1.50CM	1.51CM - 1.69CM	1.7CM<
MACHINE	79.74%	87.29%	82.81%	74.11%	64.41%
CRATES	81.67%	56.52%	85.50%	51.59%	90.91%

CONSISTENCY	Overall	0cm - 1.20cm	1.21cm - 1.50cm	1.51cm - 1.69cm	1.7cm<
MACHINE	2.28	2.65	3.21	2.08	1.53
CRATES	0.84	1.53	1.00	0.58	0.58

APPENDIX C: SORTING SPEED METHODOLOGY AND RESULTS

This appendix details the procedures and results of the sorting and feed rate experiments.

C.1 Procedure

1. Record the total mass of the nuts to be sorted through the machine.

2. Load the Feeder with a test batch of nuts. Trials used 5kg and were either loaded with the full amount or in portions of one half.

3. Run a timed trial where an operator constantly operates feeder.

    a. For portions trials, a second person can pour in the second half of the nuts into the feeder while the main operator continues to turn the hand crank.

4. Stop the time trial once the feeder doesn’t release any nuts for at least 6 seconds.

5. Record how many nuts were left in the hopper and use the recorded time and mass to determine the sorting rate in kg/min.

C.2 Results

Table C.1: Sorting Rate Portion Loading

Trial #	amount (kg)	Time taken (min)	Nuts Remaining (ct)	Sort Rate (kg/min)
1	6.1	4.38	7	1.39
2	5.1	7.5	12	0.68
3	5.1	4.6	7	1.11

Table C.2: Sorting Rate Full Loading

Trial #	amount (kg)	Time taken (min)	Nuts Remaining (ct)	Sort Rate (kg/min)
1	5.3	4.75	12	1.12
2	5.1	8.67	13	0.59
3	5.1	7.58	7	0.67

Table C.3: Sorting Rate Crate System

Trial #	amount (kg)	Time taken (min)	Nuts Remaining (ct)	Sort Rate (kg/min)
1	5.1	14.6	N/A	0.35
2	5.1	12.78	N/A	0.40
3	5.3	16.9	N/A	0.31

Table C.4: Feeder Rate Portion Loading

Trial #	amount (kg)	Time taken (min)	Nuts Remaining (ct)	Feed Rate (kg/min)
1	5.1	4	12	1.28
2	5.1	3.35	4	1.52
3	5.1	4.37	8	1.17
4	5.1	4.13	9	1.23

Table C.5: Feeder Rate Full Loading

Trial #	amount (kg)	Time taken (min)	Nuts Remaining (ct)	Feed Rate (kg/min)
1	5.1	4.88	7	1.05
2	5	5.13	7	0.97
3	5.1	4.32	12	1.18
4	5.1	3.92	10	1.30

APPENDIX D: CHI SQUARED TEST AND STATISTICAL SIGNIFICANCE

D.1 Procedure

1. Record the data of the number of kernels found in the sample of 50 nuts for Medium-SS and Medium-SL.
2. Create a joint distribution table which compares the sizes: Medium-SS and Medium SL and if the nut has more than one kernel: yes or no.
3. Use this data to create an expected frequency chart, which would be the frequency we expect if our null hypothesis were true. It is calculated by multiplying the column total times the row total and then divided by the overall total.
4. Next, the initial frequency data points and the expected frequency data points are compared to determine the chi squared value. To compute the chi square value, the following test calculations are used:
    a. Subtract observed frequency data point (x) from the expected frequency data point (y).
    b. The result of a is squared.
    c. The result of b is divided by the expected frequency (y).
    d. The sum of values from c is taken.
5. To test for statistical significance, the chi squared value is compared with a designated alpha level and degree of freedom. The alpha level is set to $p = 0.025$ as our sample size was 50. The degree of freedom was calculated using the formula: $df = (n - 1) * (m - 1)$; where n is number of columns and m is number of rows.
6. Use this alpha level and degree of freedom to determine a test value, which can be found in the Normal Distribution chart, as illustrated in Appendix C.
7. This test value is compared to the chi squared value to determine if there is statistical significance in our research hypothesis.
8. Use steps 1-7 for the Medium-Large category.

D.2 Results

Table D.1: Distribution of Medium Small Nuts by Number of Kernels found in the nuts

Kernels	**# of Kernels**		**Kernels**	**# of Kernels**
0	0		0	0
1	99		1	43
2	2		2	16
3	0		3	0

The distribution of the Medium-Small groups by the number of kernels in the nut is illustrated in Table D.1. These results are then separated into two distinct groups based on the size of the nuts: Medium SS and Medium SL, and if the nuts have more than 1 kernel: yes or no, as seen in Table D.2 below.

Table D.2: Distribution of Nuts by Sizes and by Nuts having more than 1 Kernel

Distribution by Nut Sizes			**Distribution of having more than 1 kernels**	
Nut Sizes	**Sample**		**More than 1 kernel?**	**# of nuts**
Medium-SS	101		Yes	18
Medium-SL	59		No	142

By combining these data sets into a joint distribution table, as seen in Table D.3, we were able to interpret specific data points. For example, there were 17 nuts which had more than 1 kernel but out of these nuts almost 90% were in the Medium-SL group.

Table D.3: Joint Distribution Table of Nut Sizes and Nuts having more than 1 Kernel

Joint Distribution Table			
More than 1 Kernel?	Medium-SS	Medium- SL	Total
Yes	2	16	18
No	99	43	142
Total	101	59	160

The observed frequencies recorded in Table D.3 are used in creating an expected frequency joint distribution table. The expected frequency establishes the frequency we would have expected if there was no relationship between the size of the nuts and if there are more than 1 kernel in the nut. It was calculated by multiplying the column total times the row total and then divided by the overall total. The expected frequency establishes the frequency we would have expected if there was no relationship between the size of the nuts and if there are more than 1 kernel in the nut.

Table D.4: Expected Frequency Joint Distribution Table

Expected Frequency Joint Distribution Table			
More than 1 Kernel?	**Medium-LS**	**Medium- LL**	**Total**
Yes	11.3625	6.6375	18
No	89.6375	52.3625	142
Total	101	59	160

By utilizing the observed frequency table above, we created an expected frequency table as seen in Table 4.3. Subsequently, we can utilize the observed frequency and expected frequency table to perform the chi squared calculations depicted in Table D.5; where x is observed frequency and y is expected frequency. Evidently, the chi value is approximately 23.57.

Table D.4 illustrates the joint distribution table for expected frequency. This data was then used to compare the data points for Table D.3 (observed frequency) and Table D.4 (expected frequency) by utilizing Chi Squared test calculations. As seen in Table D.5, these calculations consist of:

Table D.5: Chi Squared Test Calculations Table

Chi Square Calculations			
$x - y$	$(x - y)^2$	$(x - y)^2/x$	**Result**
-9.36	87.66	43.83	43.83
9.36	87.66	0.89	0.89
9.36	87.66	5.48	5.48
-9.36	87.66	2.04	2.04
Total			**52.23**

However, as noted in Section 6, we need a value from the Normal Distribution Chart to compare the chi squared value with. With $p = 0.025$ and $df = 1$, the test value is approximately 12.71.

The formula is $df = (n - 1) * (m - 1)$;where n is number of columns and m is number of rows.

For Table 4.3 where $n = 2$ and $m = 2$, the $df = 1$.

As our chi squared value is 52.23, which is greater than 12.706, we can conclude that there is statistical significance (with a 2.5% of error) in our research hypothesis, specifically for the Medium-Small group i.e., "There is a relationship between the size of the nuts and the number of kernels present in the nuts for the Medium-Small group".

Using the Normal Distribution chart in Appendix F, we were able to determine that with $df = 1$ and p= 0.025, the chi square value must exceed 12.706. As our chi square value is 52.23, which is greater than 12.706, we can conclude that there is statistical significance (with a 2.5% of error) in our research hypothesis, specifically for the Medium-Small group i.e., "There is a relationship between the size of the nuts and the number of kernels present in the nuts for the Medium-Small group".

This result gives us sufficient evidence to separate the Medium-Small group into Medium-SS and Medium SL.

Additionally, we utilized the chi squared test on the Medium-Large group as well. Utilizing the same computation, we computed the chi value to be 4.79, referenced in D.10. Furthermore, our normal distribution value became 3.1 as the df and alpha level remained the same for the medium-large group. Consequently, as our chi squared value remains larger than our test value, we can summarize that the results are all statistically significant.

Table D.6: Distribution of Medium Large Nuts by Number of Kernels Found in the Nuts

Medium-Large				
Medium-LS 1.5-1.65			**Medium-LL 1.65-1.80**	
Kernels	**# of Kernels**		**Kernels**	**# of Kernels**
0	0		0	0
1	13		1	3
2	20		2	17
3	0		3	0

Table D.7: Distribution of Nuts by Sizes and by Nuts having more than 1 Kernel

Distribution by Nut Sizes			Distribution of having more than 1 kernels	
Nut Sizes	**Sample**		**More than 1 kernel?**	**# of nuts**
Medium-LS	33		Yes	37
Medium-LL	20		No	16

Table D.8: Joint Distribution Table of Nut Sizes and Nuts having more than 1 Kernel

Joint Distribution Table			
More than 1 Kernel?	**Medium-LS**	**Medium- LL**	**Total**
Yes	20	17	37
No	13	3	16
Total	33	20	53

Table D.9: Expected Frequency Joint Distribution Table

Expected Frequency Joint Distribution Table			
More than 1 Kernel?	**Medium-LS**	**Medium- LL**	**Total**
Yes	23.04	13.96	37.00
No	9.96	6.04	16.00
Total	33.00	20.00	53.00

Table D.10: Chi Squared Test Calculations Table

Chi Square Calculations			
$x - y$	$(x - y)^2$	$(x - y)^2/x$	**Result**
-3.04	9.23	0.46	0.46
3.04	9.23	0.71	0.71
3.04	9.23	0.54	0.54
3.04	9.23	3.08	3.08
Total			**4.79**

APPENDIX E: NORMAL DISTRIBUTION CHART

df \ α	0.25	0.1	0.05	0.025	0.01	0.005	0.0025	0.001	0.0005
1	1.000	3.078	6.314	12.706	31.821	63.656	127.321	318.289	636.578
2	0.816	1.886	2.920	4.303	6.965	9.925	14.089	22.328	31.600
3	0.765	1.638	2.353	3.182	4.541	5.841	7.453	10.214	12.924
4	0.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	0.727	1.476	2.015	2.571	3.365	4.032	4.773	5.894	6.869
6	0.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	0.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	0.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	0.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	0.700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	0.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	0.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	0.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	0.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	0.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	0.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	0.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	0.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	0.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	0.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	0.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	0.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	0.685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.768
24	0.685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	0.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	0.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	0.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.689
28	0.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	0.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.660
30	0.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	0.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	0.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	0.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373

Figure E.1: Normal Distribution Chart used for chi square tests

APPENDIX F: PREFERENCES AND TIPS FOR MACHINE OPERATION

Obtaining the maximum sorting speed given the limitations of the roller motors will likely take a few trials worth of experience. The rollers can manage large amounts (20-30 nuts) of argan on them and still properly sort all of them without delay. However, if the feeder continually dispenses this many nuts onto the roller track at once the rollers will come to a complete stop as the torque of the motors in use are not high enough to handle the weight of the maximum potential output of the feeder. To avoid roller stoppage when large groups of nuts are dispensed, allow for a brief pause in feeder operation so that the rollers can reach full rotation speed again. Based on observation a rate of 10-20 nuts on the roller track at any given point can be maintained without slowing down the rollers.