Waste to Wealth: Repurposing Argan Nut Shells into Sustainable Solutions

An Interactive Qualifying Project Submitted to the Faculty of
Worcester Polytechnic Institute (WPI)
In partial fulfillment of the requirement for the Degree of Bachelor of Science

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Abstract

Kibbutz Ketura in Israel will produce 100 tons of argan nut shell waste annually by 2032. To valorize this waste, we researched cellulose extraction and wood plastic composite formation and conducted experiments that demonstrated proof of concept for both materials. We suggested industrial-scale processes for implementation of these methods and provided their cost-benefit analyses. Manufacturing wood plastic composites is more profitable than cellulose extraction, but both processes are viable and require further research to be properly implemented.

Acknowledgements

We would like to say thank you to Professors Isa Bar-On and Michele Femc-Bagwell for their guidance throughout our project. We could not have succeeded without you giving your time and effort to help us. We thank Professor Seth Tuler for his help in preparing us for this project, you provided us with the foundation we needed for success.

We would like to thank our sponsor, Nadav Solowey, for his support during this process and for providing us with knowledge to complete this project. Your engagement, effort, and energy put into this project motivated us to succeed.

We would not have been able to complete this project without the help of those at WPI and the Venice Project Center, including SerenDPT, who provided us with the resources to complete this project in Venice, Italy on short notice.

Our success is a direct result of the help of those mentioned above.

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Chapter 1: Introduction

Kibbutz Ketura is in the Arava Valley in Southern Israel. The Arava Valley is a barren area. To support their agriculture, Nadav Solowey is continuing his mother Elaine Solowey's work on producing sustainable crops for profit. They have successfully grown dates there and are now assessing the feasibility of growing argan trees. Argan trees grow argan fruits which consist of an outer pulp, shell, and kernel. The kernel contains argan oil, a valuable resource used in a variety of applications (Solowey, 2023).

The kernel makes up 5-8% of the nut's weight and the shell makes up roughly 90% (Nerd, 1998). There is no current use for the shells in Israel leaving them as waste. As argan oil production scales up, the amount of waste nut shells will also rise. Nadav Solowey is projecting that Kibbutz Ketura will produce 100 tons of the argan nut shells annually by 2032. It can take more than 50 years for the shells to naturally decompose in the Arava Valley environment so it is essential for the kibbutz to find a way to use the shells. The kibbutz has a similar problem with date palms, which also take over 50 years to break down. Waste palms are currently left in piles near the groves, and now stand at 6,000 tons of waste (Solowey, 2024). The waste palms have negative environmental impacts when left to decompose, contributing to water pollution, greenhouse gas release, and soil degradation (Adamu et. al., 2024). Argan nut shells may have a similar impact if a use for them is not adopted.

The goal of this project was to find a way to utilize argan nut shell waste from argan oil production while keeping the approach safe, lucrative, and environmentally friendly for Kibbutz Ketura. We created three objectives to attain this goal:

1. Carry out procedures providing proof of concept for creating Cellulose and Wood Plastic Composites (WPCs) from argan nut shells
2. Investigate the possibility of industrialization for the proposed products
3. Assess the economic impact the proposed products will have on Kibbutz Ketura

Chapter 2: Background

2.1 Agriculture in Kibbutz Ketura

2.1.1 Importance of Dates

Kibbutz Ketura is a community located in southern Israel, in the Arava Rift Valley, which receives an estimated 25 mm of rainfall per year (*Israel—Mediterranean, Arid, Semi-arid*, 1998). The lack of naturally available water is the root of multiple issues across Israel. Water quality and availability is not only a local concern, but one faced globally. The EU Commission requires that safe water is available for all use including farming in their environmental agricultural standards. It is recognized that water can be vulnerable to unsustainable abstraction, or natural fresh water usage (*Water—European Commission*, 2024). The European Environmental Agency reported that 24% of water abstraction in the EU comes from agriculture. (*Special Report 20/2021: Sustainable water use in agriculture: CAP funds more likely to promote greater rather than more efficient water use,* 2020). Kibbutz Ketura receives its water for agriculture from a fossilized aquifer, which contains saline water, limiting the number of profitable crop species able to be grown (Solowey, 2024).

Medjool dates have been a prominent part of the kibbutz's agriculture given the crops' ability to produce fruit in hot and dry growing seasons with maximum temperatures of 49.3ºC (Solowey*,* 2024). Israel is responsible for 50% of global date production, primarily from the Jordan Rift Valley and the Arava areas in southern Israel. Israel exports an estimated 42,000 tonnes of Medjool dates annually, compared to the combined exports of Jordan and the US at 25,000 tonnes. Annually, Medjool dates generate roughly $284 million USD in revenue for Israel, with half of this revenue coming from international exports (Libsker, 2020).

Dates have traditionally been a monocrop on Kibbutz Ketura. This means one type or genetic makeup of dates has been grown and harvested every year on the same land (Mary, 2022). While this can help increase yield and profits, monocrops can come with negative impacts to the environment. Monocropping can deplete the soil of its nutrients, leading to it being weakened and infertile. This forces farmers to utilize chemical fertilizers to improve crop growth. In turn, the soil becomes reliant on the fertilizer, pushing more chemicals into the environment. Growing a variety of different species can help promote growth through pest control and nutrient sharing, improving soil health (Garrity, 2020).

2.1.2 Turn to Argan

In an effort to diversify their agriculture, Ketura is working with the Arava Institute of Environmental Studies on researching and planting other crops. Dr. Elaine Solowey has spent a large portion of her life on this task. She planted over 500 species of plants and found that only ten thrive in the harsh weather conditions, including the argan tree (Surkes, 2021). Dr. Elaine Solowey began growing argan trees in 1982 in an effort to domesticate them (Farber, 2023). By controlling their pollination habits, the trees' yields can be optimized allowing for a more profitable crop. Maximizing their fruit production will utilize their low water consumption, potentially making them a suitable alternative to dates. One argan tree requires 50 L of water daily to produce fruit while each date palm uses an estimated 800 L of water per day (Solowey, 2023).

2.2 Argan Nuts

2.2.1 Argan Production

Argan nuts produce argan oil, a growing industry with the projected global market size in 2022 estimated to be $300 million USD, taking advantage of the oil's many applications ranging from cosmetics to therapeutic uses (Hill, 2023). The industry is estimated to grow up to $640 million USD by 2030 (*Global Argan Oil Market Size & Trends Analysis Report, 2030*, 2022). Moroccan argan oil is the most expensive edible oil in the world, selling for $300 USD per liter (Lybbert et. al., 2011).

Argan trees originated in Morocco where they are currently grown in a 2.5 million acre forest. The Moroccans use all parts of the trees, the wood for construction and burning, the pulp for feeding animals, the shells are burnt for energy, and the oil is sold in the cosmetic and health industries for economical gain (Perry, 2020). Morocco laid the framework for the argan oil production process in which the nuts are peeled, broken open with rocks, and the kernels are pressed in a mill to extract oil (Perry, 2020). Kibbutz Ketura is exploring modified versions of this process by experimenting with cracking and pressing machines, led by kibbutz member, Nadav Solowey (Surkes, 2021). They continue to innovate the argan oil process, including experimenting with automating nut sorting and finding a use for its bulk waste.

Utilizing nut shell waste is not only applicable to argan nut shells. Ongoing research continues to support the use of agricultural waste, proving its environmental and economic benefits. Other nut shell wastes have been studied such as walnut, hazelnut, cashew, pistachio, and oil palm shells for use in construction materials like mortar and concrete showing promise in the properties they deliver with additives (Jannat et. al., 2021).

Agricultural waste is commonly valorized through processing in biorefineries. Biorefineries create a wide range of marketable products and energy through the sustainable processing of biomass and agricultural waste (Annevelink et. al., 2022). Energy production through the use of fermentation to produce biofuels constitutes the majority of biorefinery products (Annevelink et. al., 2022). Although biofuels, such as bioethanol, represent a proven renewable and sustainable source of energy, production using argan nut shell waste is not feasible for Ketura.

Processing of agricultural waste to be suitable for bioethanol production creates additional waste which is processed into additional high-value products. The production of additional products reduces the amount of waste generated and increases revenue. Platform chemicals are commonly produced alongside biofuels (Annevelink et. al., 2022). The production of multiple products reduces waste generation and further valorizes the initial agricultural feedstock but also increases the scale and complexity necessary to create a functional facility. Facilities will process between 5,000 to more than 360,000 tons of agricultural waste annually (Annevelink et. al., 2022). The projected 100 tons of argan nut shell waste annually by 2032 in Ketura is below the amount of waste generation that would make the production of biofuels a feasible use for the waste shells.

Implementing a use for argan nut shells will provide additional economic output for the kibbutz. Another stream of income would make the argan nut operation increase revenue, possibly surpassing the revenue of dates. Finding a feasible product in the coming years will ensure that the kibbutz is prepared to scale up production as the amount of argan nuts harvested continues to grow. The kibbutz needs to establish itself both in the production and marketing of the shells to allow for the product to be profitable when full scale manufacturing begins.

2.2.2 Studied Uses

Current uses for the nut shells in Morocco were not considered for implementation in Kibbutz Ketura because they were deemed low end. These products were either single use, polluted the environment, or were unable to be scaled up with the growing amount of waste. The most common use for the shells in Morocco is to burn them for both heating and their aroma (Solowey, 2023). Burning is considered low end because it uses a mass amount of shells while not providing much economic value. Previous IQPs have explored products such as exfoliants and cat litter (Mina, 2022) however these cannot keep up with the growing amount of waste.

In order to maximize the value of the nut, we have investigated high-end uses for the argan shells. Two processes appear to be viable, and we have conducted extensive research on the following: Cellulose extraction and forming wood plastic composites (WPCs).

2.3 High-Value Argan Waste Uses

2.3.1 Cellulose

Argan nut shells are primarily composed of cellulose, hemicellulose, and lignin with each compound making up roughly 43%, 18%, and 27% of the total weight of the shell respectively (Nerd et. al., 1998). Cellulose is an organic compound made up of highly polymerized chains of sugar molecules. It is found in abundance alongside two polymeric fibers, hemicellulose and lignin, in plant biomass. The most commonly employed methods of cellulose extraction are enzyme, microbial, or acid hydrolysis (Motaung, Linganiso, 2018). Cellulose acts as the framework for the cell wall of plant cells and is found in a crystalline microfibril, thread-like form, that can be hundreds or thousands of units long. Cellulose and its derivatives are utilized in a variety of industries, ranging from biomedical applications in the form of hydrogels and drug delivery mechanisms to industrial uses in the creation of paper products and packaging materials. Clothing and fabric materials are also commonly made out of different cellulose derivatives (Ratajczak & Magdalena, 2019).

The extraction process used will vary depending on the desired cellulose derivative. Common derivatives include, but are not limited, to cellulose acetate (CA), cellulose sulfate (CS), cellulose nitrate (CN), ethyl cellulose (EC), and carboxymethyl cellulose (CMC) (Romão et. al., 2022). Many of these cellulose derivatives have potential uses as food packaging films that have been shown to extend the shelf-life and freshness of different produce (Argyropoulos, 2001). Numerous cellulose derivatives offer an opportunity to profit from growing markets while at the same time addressing the increasing amount of argan nut shell waste produced annually at Ketura.

2.3.2 Wood Plastic Composites

A Wood Plastic Composite (WPC) is a biopolymer made from wood fiber and a thermoplastic, a plastic which is pliable when heated, such as high-density polyethylene (HDPE) or polypropylene (PP). While most WPCs are made with wood flour and wood pellets as the fiber, there have been efforts to utilize nuts such as walnuts (Włodarczyk-Fligier, 2021) and pecan waste (Barbalho, 2023). Utilizing argan nut shell waste is an eco-friendly alternative for wood and other petrochemical-derived plastics that can be used in the form of furniture like chairs and decking. Experiments run by Jorda-Reolid et. al in 2023 showed that WPCs prepared with argan nut shells had improved properties compared to polypropylene. This includes increased tensile strength, and hardness. Argan-based WPCs displayed hydrophilic properties, meaning that they absorbed water. This property causes the WPCs to shrink after being exposed to water for long periods of time. One way to lower the hydrophilicity is by adding a compatibilizer, or another polymer in small amounts (Jorda-Reolid, 2023). Compatibilizers are used in order to make two compounds mix better or take on desired properties, such as hydrophobicity.

Although WPCs have a higher production cost than lumber, their maintenance cost is lower causing WPCs to be less expensive over time (Markarian, 2005). WPC sales made up $6 billion USD globally in 2023, showing the value for these composites. WPCs will grow in popularity as environmental issues grow. They are expected to reach $15.5 Billion USD in 2030 (Kunz, 2023). There is not enough natural wood to support new items such as decks, furniture, and fences. Israel in particular could benefit from the use of WPCs as their harsh climate requires normal maintenance and replacements for their large sector of wood decks and plastic outdoor furniture (Blackshaw, 2020). WPCs would decrease the environmental impact from these products as well as last longer without maintenance and replacement.

The environmental strain of WPCs can be lowered further by using bio-polymers for production. Plastics make up 10 million tons of nonbiodegradable waste, which are dumped into the ocean every year. This continues to cause a major strain on the ocean's ecosystem. (Atiwesh, 2021). While petrochemical polymers are more common due to quick and affordable production, bio-polymers are a growing industry as concerns are continuously raised to create more environmentally-friendly alternatives. There have been many efforts to make the bio-polymer synthesizing process cheaper to help push this idea further, garnering a lot of attention in the last few decades (Jorda-Reolid, 2023).

Further studies on cellulose and WPCs produced from argan nut shell waste have potential to create a profitable product. They are both used as building blocks for a variety of uses, allowing Kibbutz Ketura to sell them both pure and as larger products.

Chapter 3: Methods

In evaluating the feasibility of our proposed solutions, we carried out the objectives mentioned with research and testing. Procedures were limited due to a relocation from Israel to Venice, Italy. In Italy we worked in the Venice Project Center (VPC). With no accessible lab space, we followed procedures using materials that were available in local stores and could be used safely.

3.1 Extracting Cellulose

3.1.1 Cellulose Experiments Conducted at the VPC

Two procedures were conducted to assess the efficacy of extracting cellulose from argan nut shells, which required the same materials listed in Table 1. In one procedure, we created 100 mL of 0.6M aqueous sodium hydroxide (NaOH) by mixing 2.5 g of caustic soda in 100 mL of water. Argan nut shells were submerged in the solution and left to sit outside in an ambient temperature ranging from 5-10ºC for 9 days.

Table 1

Cellulose Extraction Materials

1. Mason Jar
2. Argan Nut Shells
3. Caustic Soda (Sodium Hydroxide)
4. Tea/Coffee Filter

Another procedure we conducted involved a similar solution with a 1.95M aqueous solution of NaOH. This was made by mixing 7.8 g of caustic soda with 100 mL of water. An ice bath was prepared with a water solution containing 15% salt by weight and its temperature cooled to -6ºC. We added crushed argan nut shells to the NaOH solution, which was submerged in the ice bath. The solution was stirred every 2 minutes for 2 hours to maintain the temperature at -6ºC. A syringe was used to transfer the liquid to a separate container to sit for 5 days. The cellulose was filtered out of the solution and dried.

3.2 Forming a WPC

3.2.1 WPC Experiments Conducted at the VPC

We created four composites with different ratios of polypropylene to argan nut shells using the materials listed in Table 2. The composites were prepared by breaking down argan nut shells with a hammer. We did this with raw shells for two samples and one sample cooked at 170-180ºC. This process could not be maintained with our equipment due to the hardness of the shells. We softened the shells when creating the fourth sample to ease the breakdown process by boiling them in water for two hours and oven-dried them once crushed. The shell particles were mixed into polypropylene which had been melted in an oven at 170-180ºC. We mixed the two materials in a bowl, reheating the mixture when it became too stiff to mix further. The final mixture was added to a cylindrical candle mold to cool and take shape as a WPC. We created a control sample with pure polypropylene by melting and shaping it to compare it with the WPCs.

Table 2

Wood Plastic Composite Materials

1. Polypropylene Pellets
2. Crushed Argan Nut Shells
3. Candle Mold

This process was conducted with the following ratios:

1. ~ 60:40, consisting of 12 grams of polypropylene and 8 grams of nut shell powder
2. ~ 70:30 consisting of 20 grams of polypropylene and 8 grams of roasted nut shell powder
3. ~ 80:20, consisting of 12 grams of polypropylene and 3 grams of nut shell powder
4. ~ 80:20, consisting of 12 grams of polypropylene and 3 grams of boiled nut shell powder

3.2.2 WPC Materials Testing

We conducted tests to gauge the strengths of the WPC samples. We sanded the samples to create a flat and smooth surface, reducing possible errors from surface irregularities. We used nails to cut into the sanded surface. Any scoring was noted in order to gather information on the hardness. We hit a nail into the samples, noting indents to test resistance to penetration.

We tested their hydrophilicity by running them under water for five minutes and soaking them in water for three 10-minute intervals. Tests were done between each water exposure period, bending, scratching, and attempting to puncture them. Results of these tests were collected to record the effect of short-term water exposure on their properties.

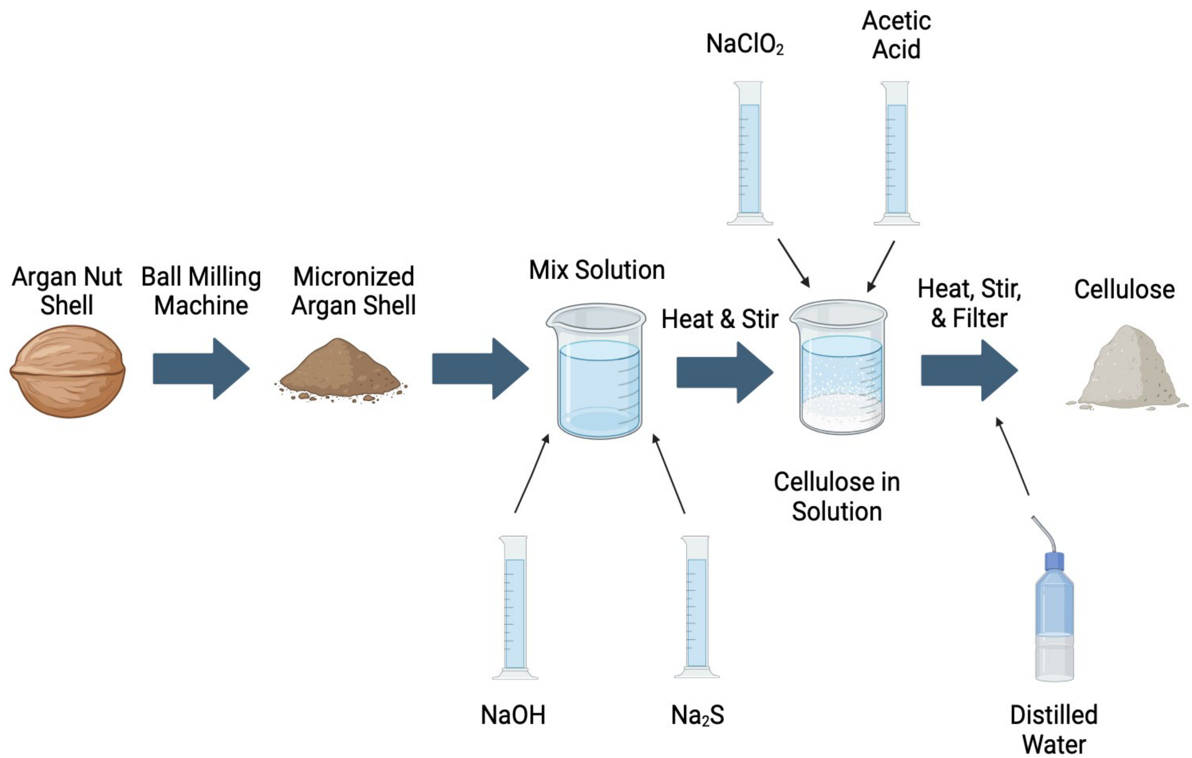
Chapter 4: Large Scale Production Processes

4.1 Cellulose

Industrial cellulose production is often carried out through a process known as Kraft pulping, which is a chemical process that can turn the argan nut shells into pulp consisting of cellulose. Kraft pulping is the extraction and purification technique that we would have preferred to carry out, but we did not have access to the equipment necessary to conduct these industry-standard procedures (Femina, 2023). This process relies on the chemicals in Figure 1 that were obtainable, but we did not have adequate facilities to properly and safely handle them. Safety measures would have included proper ventilation in the form of a fume hood, personal protective equipment (PPE), tools to analyze any resulting products, and lab equipment including glassware, hot plates, and stir bars. Many variations of the Kraft pulping procedure exist, but one we would have carried out is as follows:

Figure 1

Kraft Pulping Process



Procedure:

In a 250 mL beaker, 1 g of pulverized argan nut shells is added to a solution containing 6% weight by volume (w/v) Na_2S solution and 8% w/v NaOH solution. This mixture is stirred at 95℃ for 3 hours. The solution is filtered and neutralized with distilled water in order to obtain a sample of pure cellulose. Optional bleaching steps may be carried out in order to improve the color and quality of the sample. Bleaching is carried out using a 3% solution of $NaClO_2$ and as much acetic acid necessary to maintain a pH of 3-4. This solution is mixed at 90℃ for one hour, filtered, and washed with distilled water.

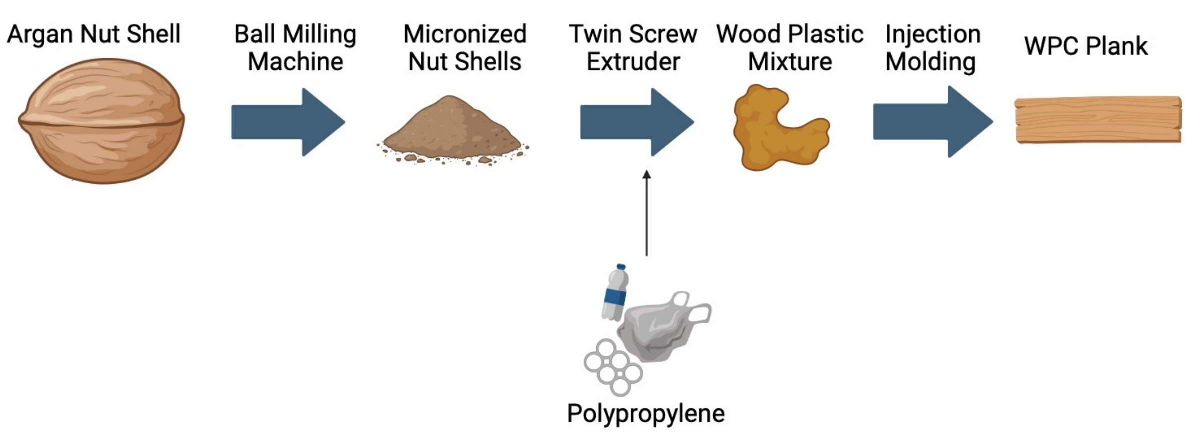
This procedure is not reflective of the one typically seen in industrial-level production of cellulose, but would have demonstrated that the extraction of cellulose from argan nut shells is feasible with proper lab space (Akhlaq, 2023).

4.2 Wood Plastic Composites

The production procedure we carried out for WPCs was modified to fit the capabilities we had in Venice. The recommended procedure requires an investment in the equipment necessary to create high quality WPCs. This includes a ball-milling machine, a twin-screw extruder, injection molding machine, and a compatibilizer, polypropylene grafted maleic anhydride (PP-g-ma) (Jorda-Reolid, 2023). The recommended procedure is based on experiments carried out by Jorda-Reolid et. al and would run as follows:

Figure 2

Industrial WPC Process



Procedure:

The argan nut shells are loaded into the ball milling machine to micronize them with particle sizes less than 100 micrometers. The micronized argan nut shells (MAS) are loaded into a twin-screw extruder with the polypropylene and PP-g-ma, heated to around 170ºC, and mixed together. The mixture would go through the injection molding machine to be formed and cooled for use as a wood plastic composite. The wood plastic composites would take the shape of the desired mold, which would be cylindrical or planks.

Chapter 5: Results & Discussion

5.1 Cellulose Production

Our initial procedure did not generate meaningful results. The solution in the jar became darker over several days and while there were particles in the jar, we predicted it was primarily due to the nut shells being progressively softened and deteriorating. We did not observe anything in the solution, seen in Figure 3. that was indicative of any cellulose particles. Since we were unable to identify any cellulose, we ended the procedure and began conducting another.

Figure 3

First experiment conducted on extracting cellulose from argan nut shells

Similar to the first procedure, the second procedure also resulted in a darkened solution. As seen in Figure 4, the solution was darker and formed a noticeable precipitate. Along with this, we were able to observe noticeable white particles. Based on literature we had read, the precipitate seemed to be indicative of cellulose being extracted. After filtration and drying, we observed the crystals, as seen in Figure 5. The particles shown in Figure 6 are assumed to be cellulose before further processing. We could not further characterize the product beyond this point due to the lack of available facilities to perform further analysis.

Figure 4

Solution for precipitate collecting at the bottom of the dish

Figure 5

Remaining portion after liquid fraction was filtered off

Figure 6

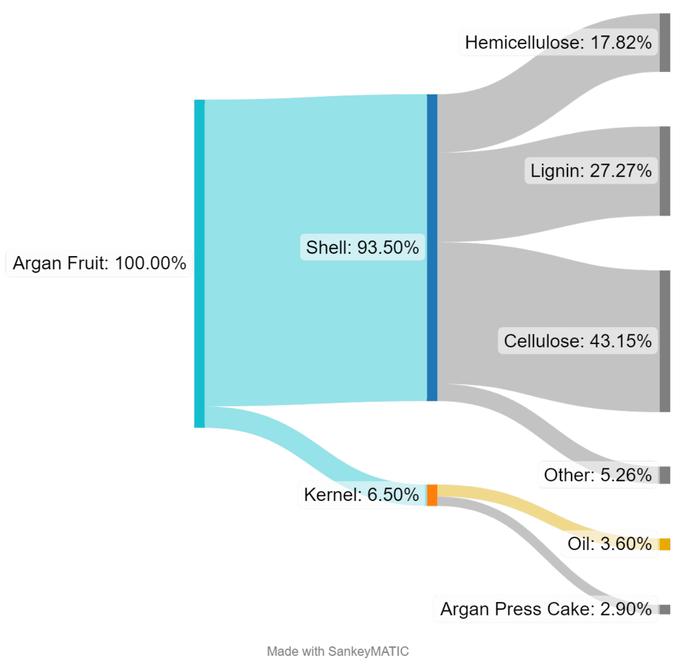
Collected product assumed to be cellulose before further processing

5.2 Argan Nut Shell Components

Argan nut shells are primarily composed of lignin, cellulose, and hemicellulose as seen in Figure 7. The Kibbutz can break down the nut shells into the primary components and sell them to a processing facility for further valorization. Agricultural biomass that is processed and converted into value-adding products is commonly referred to as lignocellulosic feedstock (LCF). Argan nut shell waste will be referred to as LCF for the purposes of this section. LCF is commonly used as the industrial raw material for bio-based energy, material, and chemical production. The use of LCF as the raw material for bio-based products is desirable due to the low cost, easy material sourcing, and utilization of what would otherwise become waste products. It is necessary to separate LCF into its primary components, consisting of cellulose, lignin, and hemicellulose, before it can be utilized. Each of these primary components has many potential valorizing uses and a better understanding of why each component is valued has been provided below.

Figure 7

Argan Fruit Composition % by Weight



Cellulose:

Cellulose is often the primary component of LCF. As of 2015, annual global cellulose production was ~1.5 trillion tons (Maity, 2015). Cellulose produced by plants is referred to as native cellulose (Lavanya et. al., 2011). Interest in potential applications of cellulose continues due to cellulose having good mechanical properties, low material density, and being biodegradable (Lee et. al., 2009). Cellulose is used in paper making and the production of composite materials (Lee et. al., 2009). Efficient cellulose extraction from LCF should incorporate the removal of the lignin and hemicellulose components (Chopra, Manikanika, 2022).

Hemicellulose and Lignin:

Hemicellulose acts as a linkage material between cellulose and lignin (Chopra, Manikanika, 2022). Pretreatment of LCF increases the efficiency of isolating cellulose from hemicellulose and lignin (Souza et. al., 2019). It is possible to recover the lignin and hemicellulose components during pretreatment. Lignin recovery rates can reach up to 75% (Chen, 2015). Lignin may be further processed for the production of high-value chemicals (Chen, 2015). Hemicellulose recovery rates can reach up to 80% (Chen, 2015). Recycled hemicellulose can be further processed for fermentation or sale directly (Chen, 2015).

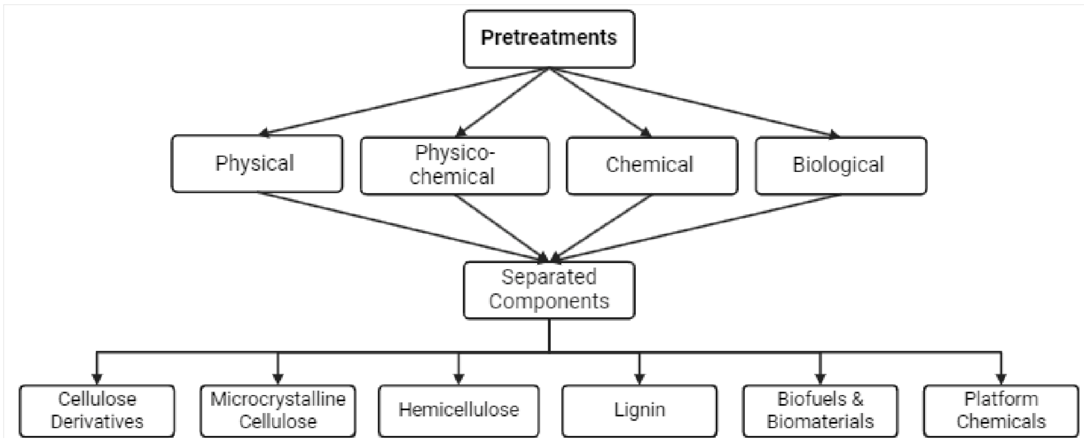
5.3 Pretreatment

5.3.1 Pretreatment Reason

For LCF to be fully utilized for the production of any products, it must undergo a series of pretreatment steps. As seen in Figure 8, these pretreatment steps commonly fall into a physical, physico-chemical, chemical, or biological category (Talebnia, 2010). Pretreatment of the material increases the maximum potential product yield that can be obtained and decreases the amount of time and chemicals necessary for the extraction and separation of components composing the feedstock (Gallego-García et. al., 2023). In many cases pretreatment allows for yields greater than 70% for the desired product and energy savings of up to 98%, making pretreatment a necessary step to make cellulose isolation profitable (Gallego-García et. al., 2023).

Figure 8

Pretreatment and Resulting Products



5.3.2 Physical Pretreatment

Physical pretreatment of the argan nut shells is necessary to create a viable cellulose extraction process that does not use an overabundance of time, energy, and other resources. An analysis of variance conducted by Galiwango et. al. on the extraction of cellulose and α-cellulose from date palm waste revealed that 95.47% of the obtained cellulose yield was due to the concentration of chemicals being used, the part of date palm waste being used, and the size of the particles (Galiwango et. al., 2019). Argan nut shells are the only part that would be processed on the kibbutz, meaning particle size will have the largest impact on the potential yield of any process that is employed, with an estimated impact of 41.53% towards the total yield (Galiwango et. al., 2019). Mechanical pretreatment must be used to break down the shells into particles with an ideal size of 300 μm or less.

The most common forms of mechanical pretreatment through milling have been highlighted in Table 3. Certain milling methods were not researched in depth due to immediately apparent disadvantages associated with them that would prevent their implementation from being feasible at Kibbutz Ketura. These disadvantages included limits in smallest achievable particle size, unreliability of the machine, and lack of supporting literature.

Table 3

Common Physical Pretreatment Advantages and Disadvantages

Non-recommended Milling Techniques	**Advantages**	**Disadvantages**	**Smallest Average Particle Size Reached**
Disc Refiner	• Small particle size	• High energy dissipation rate • Least reliable method • Not commonly used for cellulose extraction	120 µm
Screw Extruder	• Has been used to obtain microfibrillated cellulose	• Size reduction down to 1.4-8 mm particle size is necessary	*N/A*
Knife Mill	• Widely used due to high production rate and ease of use	• Moisture content can cause issues with flow of feedstock	100 µm
Roll Mill	*N/A*	• Mainly used for flour production • Only good for brittle or fibrous biomass	17.25 µm
Centrifugal Mill	*N/A*	• Not commonly used for cellulose extraction	2.5 mm
Recommended Milling Techniques	**Advantages**	**Disadvantages**	**Smallest Average Particle Size Reached**
Ball Mill	• Extensively used • Initial particle size can be very large • Chemical treatment can be used at the same time	• Low energy efficiency relative to production capacity	20 µm
Rod Mill	• Chemical treatment can be used at the same time	• Not commonly used • Use 30% more power than a ball mill	50 µm
Hammer Mill	• Energy Efficient • Has been used specifically for cellulose extraction from argan shells	• Moisture content can cause issues with flow of feedstock	62 µm

Note. Data are from Ämmälä et. al., 2019, Miao et. al., 2011, Kratky, 2022, Liu et. al., 2020, Bouhoute et. al., 2021, and Gallego-García et. al., 2023

5.3.3 Further Pretreatment

Further pretreatment must be carried out in order to deconstruct the cellulose-hemicellulose-lignin structure into separate components (Chen, 2015). Biological pretreatment procedures using enzymatic reactions have large costs associated with obtaining the necessary enzymes (Reshmy et. al., 2022). Chemical pretreatment is often selective towards one compound, wasting an opportunity to valorize every LCF component (Chen, 2015). Biological and chemical pretreatments are best avoided to minimize excessive cost and environmental pollution.

Physico-chemical pretreatment can reduce or eliminate the amount of necessary chemical reagents. Steam-explosion (autohydrolysis) treatment has been used in the development of many cost-effective refining procedures. High pressure and temperature water can be used to degrade the hemicellulose into a water-soluble fraction that can be further processed to produce other high-value products (Chen, 2015). The remaining solid fraction after autohydrolysis is rich in lignin and cellulose that can be treated further. Experiments have been conducted on the extraction of cellulose, lignin, and hemicellulose from walnut shells using autohydrolysis followed by organosolv delignification, the use of organic solvents for biomass conversion, demonstrating a potential procedure we could apply to argan nut shells (Chen, 2015).

Autohydrolysis of walnut shells at 210 °C carried out by Morales et. al. achieved a hemicellulose yield of 71.8% (Morales et. al., 2022). Organosolv delignification of the auto hydrolysed walnut shells resulted in a relative yield of 59.8% for lignin and a 40% conversion of cellulose to cellulose nanocrystals. The use of argan nut shells is likely to result in different yield percentages from those obtained using walnut shells. Experimentation and optimization of a modified version of the procedure carried out with walnut shells can potentially result in increased yields.

5.3.4 Environmental Considerations

Steam explosion primarily requires the use of liquid hot water along with a few acids and other additives, if desired, that can enhance the efficiency of the process and maximize extraction such as acetic acid, sulfuric acid, and carbon dioxide (Shah et. al., 2022). These chemicals aren't environmentally harsh showing this process as an environmentally friendly alternative to more mechanical processes (Marques et. al, 2020). The use of organic solvents like acetic acid, also known as organosolv as mentioned earlier, is a much greener alternative compared to other pulping processes as it is associated with less pollutants and overall has a lower environmental impact. Across several pieces of literature, steam explosion has been reported to have lower costs compared to other pretreatments as well as decreased energy consumption (Marques et. al, 2020) of up to 70% compared to mechanical treatments (Ziegler-Devin et. al., 2021).

The main concern with the steam-explosion process comes down to byproducts that occur during the process. Fermentation inhibitors, such as furfural, can occur as a byproduct of steam-explosion (Teixeira et. al., 2014). Fermentation is important to convert the components of LCF into biofuels which is why these byproducts can become a concern. Detoxification methods for the inhibitors have been developed using water, methanol, or a biological approach (Asada et. al., 2021). While this is a solution to the issue, it can raise the concern of more water usage and more chemical use for the process. Israel's aquifers are already being overused, leading to further salination of the water needed for the crops and detoxification would only increase water usage. On a larger scale, this requires further investment into more materials in order to detoxify byproducts that limit biofuel fermentation as well as further attention being raised towards proper disposal of these materials, especially if environmentally harsh chemicals are used. Biofuels are not the focus product for the kibbutz, however this is mentioned as steam-explosion is primarily used for production of biofuels.

5.3.5 Social Considerations

Utilizing the steam explosion process on Kibbutz Ketura can be a step towards valorizing the nut shells. Extracting each component and potentially selling it to another company will be a good use of the nut shells. Although dates are an established agricultural sector on the kibbutz, introducing the use of the nut shells can also aid in pushing the agenda for further adoption of the argan agricultural sector while maintaining the date market. The kibbutz could see how cellulose is utilized in their everyday lives such as towels, paper, fabrics, medications, and the food they eat (PCC Group, 2023). This could build the kibbutz's preference for greener products as they become more aware of how detrimental plastic-based items are to the environment. Building awareness of bio-based products and their benefits is a challenge faced in many places. A study conducted in the EU in 2021 showed that people overall lacked awareness of what bio-based products are and what goes into making them due to lack of information (Fernández et. al., 2023). This could lead to people believing that bio-based products are more expensive to invest in and potentially be of a lower quality compared to plastic-based products (Annevelink et. al., 2022). Implementation of steam-explosion can be an educational opportunity for everyone on the kibbutz. By selling the extracted components of the nut shells, the kibbutz will have the opportunity to see the utilization of the nut shells in products they need and use.

5.3.6 Economic Consideration

The production of a single product made from cellulose extracted from argan nut shells would result in the lignin and hemicellulose fractions being treated as waste products. The production of products that utilize each fraction of the argan nut shell will further mitigate waste generation by using what would otherwise be waste lignin and hemicellulose byproducts.

Hemicellulose may be further refined into xylooligosaccharides (XOS), with a minimum selling price (MSP) of $3.43 to $7.50 USD per kilogram (Lan et. al., 2021). Lignin has a MSP of $1.08 USD per kilogram and CNC has a MSP of $6.43 per kilogram (IndustryARC, n.d.; Fernández Méndez et. al., 2023). Producing 100 tons of argan nut shell waste per year would lead to the production of 7,900 kg of XOS, 13,300 kg of lignin, and 18,000 kg of CNC, shown in *Table 4*. The potential revenue from selling these products is $173,000 and $208,000 USD per year.

The cost of creating a processing facility for argan nut shells has a variable range of initial capital costs. Wolbers et. al. found that similar processing facilities have capital costs ranging from $46 USD to $234 USD per ton of annual processing, with a variable 5-24% cost increase associated with steam explosion processing (Wolbers et. al, 2018). The capital cost range for Ketura using this range would be between $4,600 and $29,000 USD. The combined costs of energy, water, and steam heating has been calculated to be close to $20,000 USD annually (Fernández Méndez et. al., 2023). The additional cost of labor would be at least $12,500 USD per year (Fernández Méndez et. al., 2023).

The annual expenses of operating a shell waste processing facility bring estimates for yearly profit down to $140,500 to $175,500 USD. These estimates have been made with the assumption that Ketura would be able to sell each product at the stated MSP and that the production process has been fully optimized. These estimates also do not include the cost of labor and additional resources. Reduction in yield, decreases product MSP, and increases in annual operating costs can have dramatic effects on profit margins, as seen in *Table 4*.

Table 4

Combined Impacts of Profit-Reducing Variables

Initial estimated annual cost range	**$173,000 - $208,000 USD**
20% Yield Reduction	**$70,765 - $90,882 USD**
20% Yield Reduction + 30% Increase in Annual Operating Costs	**$64,888 - $83,910 USD**
20% Yield Reduction + 30% Increase in Annual Operating Costs + 30% Decrease in Product Price	**$37,881 - $51,096 USD**

The ability to create the aforementioned products using ANS and the described process is not guaranteed. We highly recommend that further research be conducted on how argan nut shell waste may be processed. The production of a single cellulose product is not feasible, and will generate additional waste products that will require specialized disposal. Utilizing the hemicellulose and lignin portions of the argan nut shell will decrease the amount of waste generated. However, the complexity of the necessary processing procedure and the associated costs will be increased. Given the uncertainty and large number of estimations and assumptions we made, we recommend that Ketura explore opportunities to valorize the entire argan nut shell by drawing inspiration from established biorefinery processes. Further research on the specific requirements for creating a successful facility in Ketura to process the argan nut shells is necessary.

As of 2021, argan nut shells could be sold at a price of $0.05 USD/kg in Morocco (Bouhoute et. al, 2021). Potential profits for Ketura selling the unprocessed shell waste could reach $4,500 USD per year. We recommend that Ketura research potential opportunities for selling the unprocessed argan nut shell waste to a facility that has an established agricultural waste processing procedure if processing the shells on the kibbutz is not pursued further.

5.4 Wood Plastic Composite Production

5.4.1 Wood Plastic Composite Production Results

Table 5 shows the composition, shell preparation methods, and the properties of each composite.

Table 5

Composites and their properties

Composite #	Ratio PP:Shells	Ratio in Grams	Preparation	Properties
1	60:40	12:8	Raw	Brown, Poor Dispersion
2	70:30	20:8	Baked	Dark brown, Good Dispersion
3	80:20	12:3	Raw	Light Brown, Poor Dispersion
4	80:20	12:3	Boiled	Brown, Great Dispersion

Composite #1 was the hardest to form due to the high percentage of raw argan nut shells. This sample, shown in Figure 9, has visible, large particles of nut shell while not being mixed as well as the other samples. It needed to be remelted four times during the mixing phase, resulting in a color darker than the other raw and boiled composites but lighter than the baked. This sample had a rough texture before sanding.

Figure 9

Composite #1

The formation of *Composite #2* resulted in a dark colored, glossy sample as shown in Figure 10. The dark color can be attributed to the nut shells being roasted before we crushed them which darkened the shells. The roasted shells could be broken down finer than raw shells allowing for an easier mixing process and therefore better dispersion of the particles. The texture of this sample was rough before sanding.

Figure 10

Composite #2

Composite #3, as shown in Figure 11, has a light color with the translucent property of polypropylene visible throughout. This is due to the larger particle shells from raw preparation as well as a low ratio of polypropylene to nut shells in this sample. The surface of this composite was coarse before sanding.

Figure 11

Composite #3

Composite #4 has the least surface deformations. Boiling the nut shells was an effective way to create a powder, which made mixing the easiest of the four samples. This is reflected in the even dispersion of nut shell particles, seen in Figure 12. We did not have the equipment to know when they were dry, so the color may be slightly darker than if the nuts had been ball milled instead of boiled. This composite had a smooth texture after being molded.

Figure 12

Composite #4

A control sample of 100% polypropylene was formed by melting polypropylene pellets in the oven and then shaping them to the candle mold, seen in Figure 13. The texture of this sample was initially smooth after molding. This was done to compare results of the materials tests with the wood plastic composite samples.

Figure 13

Pure polypropylene shaped in the candle mold

5.4.2 Materials Testing of WPCs

The materials testing we conducted on the dry WPCs did not show differences regarding hardness. All of them were scratched and indented with nails showing low hardness. We wanted the composites to display high hardness, or take high effort to scratch. After running the composites under water for five minutes, they were easier to scratch but there was a negligible change in ease of puncture. Each of the 10-minute soaking periods resulted in all samples to be easier to scratch than before exposure to water, but no negligible difference from each other. The ability to puncture remained stagnant throughout all trials. There was negligible difference between the results of the different WPC samples. None of the scratches or puncture marks were deep enough to see in pictures. WPC samples #1,2, and 4 all became slightly darker after water exposure, signifying that there was absorption, as seen in Figure 14.

Figure 14

WPCs 1-4, respectively, and PP sample after water exposure

5.4.3 Wood Plastic Composite Discussion

Wood Plastic Composites are used in a variety of products, ranging from small things such as coat hangers to larger uses like construction materials. We are focusing on the larger products to maximize profit for Kibbutz Ketura. The product list that we recommend for the kibbutz is furniture and decking. Future studies will require further materials tests with professional equipment. Finding quantities for tensile strength, ductility, and toughness before and after prolonged exposure to UV rays and water will allow for a more thorough understanding of the composites' properties and fitness for decking and furniture. The differences between preparation methods and ratios of polypropylene to argan nut shells on the products' properties can be studied with access to materials testing results.

Polypropylene is not a renewable polymer, so its environmental impact is high. Future studies should be done to find a greener alternative for the composites. Biodegradable polymers such as polylactic acid or bio-polypropylene have potential to lessen the environmental strain of WPCs (Schwarzkopf, Burnard, 2016). Recycled plastic can also lessen the environmental impacts of WPCs. Recycled PP has shown to reduce the impact of WPCs on global warming as well as use less abiotic resources (Ramesh et. al., 2022). Choosing to manufacture WPCs with a bio-polymer or recycled polymer requires further research on the effect that will have on the materials properties and cost of production.

Furniture is expected to produce $3.5 Billion USD in revenue for Israel in 2024. The market for furniture is still growing with a projected compound annual growth rate (CAGR) of 3.57% through 2028, growing to $4 Billion USD of revenue in 2028. The biggest sector is expected to be living room furniture, reaching $1 Billion USD in 2028 (*Statista Market Forecast, n.d.*). The most attractive sector could be outdoor furniture as it is found throughout Israel, mainly made of plastic. A study using WPCs formed with beech wood showed that UV rays had negligible effects on the tensile strength and elastic modulus of a sample after prolonged exposure (Hirsch, 2022). Further experiments need to be run with argan nut shell incorporated WPCs in order to determine if they exhibit the same properties. A UV resistant WPC has potential to be profitable in the furniture market.

Decking is a promising product for Kibbutz Ketura to explore. Plastic composite decking earned $3.6 Billion USD in 2022. The market is expected to be valued at $8.9 billion USD in 2030 with a CAGR of 10.2% until then (Global Composite Decking Market Report 2022, 2022). Israeli buildings incorporate outdoor spaces with residents often having decks attached to their houses (Bar-On, 2024). Maintenance on large products such as decks can be time consuming and costly, a low maintenance option may attract consumers. Providing residents with an option for a cheap and sustainable WPC option for decking has potential to be profitable.

Creating profitable wood plastic composite products will require initial capital investments. The injection molding process with argan nut shells and polypropylene needs three large machines for production. A ball milling machine costs ~$1,000 USD (Alibaba, 2024) and twin-screw extruder as well as the injection molding machine will each need an investment of $10,000-$25,000 (Alibaba, 2024) USD. The total cost of machinery for an industrial WPC production process is $21,000-$51,000 USD. Polypropylene costs about $3,200 USD/ton (Poli Plastic Pellets, 2024). If a pp-g-ma compatibilizer is needed it costs ~$2.50 USD/kg (Alibaba, 2024). Assuming a ratio of 1 kg pp-g-ma to 10 kg polypropylene, about 90 kg ($225) pp-g-ma will be needed/ton of PP bringing production costs to ~$3,500 USD/ton of polypropylene. A worker on the kibbutz is paid about $14 USD/hr, so there will be an added cost of wages which will vary based on the scale of production (Solowey, 2024).

High-quality furniture and decking made out of wood plastic composites can be sold for a large profit margin to offset production costs. A chair sells for $90-$200 USD and tables for $250-$700 USD (Boulevard Outdoor Inspirations, n.d.). A break-even point (BEP) can be reached with 300-600 $90 chairs sold. With a mixture of high quality products a BEP can be reached with less product. Pure decking sells for $12-$33 per square meter, allowing for an BEP after 2,000-4,500 m^2 (UNFLOOR, n.d.). Charging for installation and other services could be an opportunity to break even quicker.

We calculated the costs and revenue for four different ratios of WPCs, which can be found in table 6. The most aesthetically wood-like sample we created was sample #4, so the sample calculation is done with an 80:20 ratio of PP to nut shells. This used a ratio of 80:20 polypropylene to argan nut shells. Without accounting for a compatibilizer, 100 tons of nut shells will require 400 tons of polypropylene for WPC production. This will result in $1.3 million USD being spent per year on polypropylene per year when the production is scaled up to the projected nut shell waste in 2032. Paying five workers $15 USD per hour and assuming 40 hour workweeks for 52 weeks a year to work on this will cost an additional ~$150,000 USD per year. We doubled that to account for high worker benefits in Kibbutz Ketura, costing a total of $300,000 USD. The average weight of one small wooden table is around 25 kg (Yale University, n.d.). The average density of wood is .59 g/cm^3 meaning each table has a volume of .042 m^3 (Barreiros et. al., 2023). The composite is made up of argan nut shells and polypropylene with densities of .596 g/cm^3 (Najah EL Idrissi et. al., 2023) and .9 g/cm^3(Saiz-Arroyo et. al., 2013) respectively. An 80:20 ratio of PP to nut shells has a density of .84 g/cm^3. With 500 tons of composite expected to be produced in 2032, there will be around 54,000 m^3 of WPC created. Roughly 13,000 tables can be created from the 80:20 ratio for WPCs.

If all of these are sold at the low end of the price range, Kibbutz Ketura will have an estimated profit around $1.6 million USD without factoring in the initial cost of equipment. Scaling this down to the 10 tons of waste expected to be produced in 2024, the operation would lose about $100,000 USD for the lowest quality tables with the majority of costs being in workers. A realized profit is expected to differ from this projection if sales are kept local. These are very rough estimates from market averages, reaching this potential would still take years to reach due to an adjustment period before full-scale production can be implemented. We recommend that this number be examined further and adjusted to include factors such as energy, space, workers benefits, cost of money, and measured quantities of materials needed for samples of each product.

Table 6

Projected Revenue and Profit for Multiple WPC Makeups (100 tons of waste)

Ratio PP:Nut Shell	Revenue (Low)	Revenue (high)	Profit (low)	Profit (High)
90:10	$6,200,000	$17,200,000	$3,000,000	$14,100,000
80:20	$3,200,000	$8,900,000	$1,600,000	$7,300,000
70:30	$2,200,000	$6,100,000	$1,100,000	$5,100,000
60:40	$1,700,000	$4,800,000	$900,000	$4,000,000

This scale of production may not be possible for the kibbutz, so outsourcing the shells to a production facility is a possibility to consider. UBQ is a company located near Tel Aviv, Israel which specializes in creating plastic out of biowaste such as banana peels and chicken bones. We reached out to them but received no reply. While UBQ doesn't state that they make WPCs, they- or a similar company- may be better equipped to handle the 500 tons of composites expected to be created per year. Getting in contact with a buyer who produces WPCs is another route, possibly forming a partnership for supplying the argan nut shells as a wood fiber.

There is potential for profits from turning argan nut shell waste into wood plastic composites. The growing market for WPC products globally and within Israel provides opportunity for the kibbutz to sell their products. Studies in the future will need to carry out the WPC production process with proper equipment and conduct materials tests in order to confirm our recommendations. Although the process requires an initial investment, we estimate that the potential revenue could turn a profit in about 3 years of optimized full scale production. Partnering with another manufacturer is a potential option if this scale can not be reached on Kibbutz Ketura. If neither of these are determined to be feasible, WPCs remain an option to be studied for Kibbutz Ketura as their market is projected to reach $12.5 Billion USD by 2030 (Hosseini, 2023).

Chapter 6: Conclusion

We were able to provide proof of concept samples of both cellulose and wood plastic composites from argan nut shell waste. Due to our relocation to Venice, Italy these were not done through the same procedures that we would have carried out in a lab setting. We simplified the procedures to be done inside of a standard kitchen with equipment that could be bought in local hardware and variety stores.

We ran the same experiment in two different conditions for extracting cellulose from the argan nut shells. One of them was unsuccessful and one of them produced what we presume to be cellulose. We recommend that further studies be done to explore and refine the process for extracting cellulose. Steam-explosion (autohydrolysis) is a process that may be suitable for the kibbutz. It offers an environmentally friendly way to extract the major components from argan nut shells compared to other pretreatment methods. The kibbutz can sell the components which will be further valorized into high-value, sustainable products.

Based on research and the results from the procedures we carried out, we recommended a process to be carried out for large-scale production WPCs. The process requires new and costly machinery for Kibbutz Ketura. A cost-benefit analysis was created in order to evaluate the required investment for production. The analysis took the two recurring costs of polypropylene, worker's wages, and worker's benefits into consideration. Both furniture and decking have high profit margins and are of use in Israel. Outdoor furniture is mostly made of plastic, which is sensitive to UV rays. This provides a chance for WPCs to be a more sustainable replacement in the large outdoor furniture market. WPCs have lower environmental effects than plastics which also could make them a better option than plastics for furniture. We recommend that future studies evaluate the material properties of WPCs made from argan nut shells including their UV resistance. WPCs ability to survive in the sun is important towards their potential use in outdoor furniture and decking in Israel.

Both WPCs and lignocellulosic products can be developed from argan nut shells. They are both profitable at full-scale production but will take years to reach that point. Further research on the feasibility for Ketura to reach large-scale production of either product is required before implementation. If it is not feasible to produce either on the kibbutz, the nut shells should be outsourced to established facilities.

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Appendices
Appendix A

Cellulose Economic Calculations

Initial estimated annual cost range	**$173,000 - $208,000 USD**
20% Yield Reduction	**$70,765 - $90,882 USD**
20% Yield Reduction + 30% Increase in Annual Operating Cost Increase	**$64,888 - $83,910 USD**
20% Yield Reduction + 30% Increase in Annual Operating Costs + 30% Decrease in Product Price	**$37,881 - $51,096 USD**

Table A1. Combined Impacts of Profit-Reducing Variables & Estimated Annual Cost Range

Argan Shell Composition %		
Hemicellulose	**Lignin**	**Cellulose**
17.82	27.27	43.15

Table A2. Nut Shell Composition of Hemicellulose, Lignin, & Cellulose

% Conversion		
Hemicellulose	**Lignin**	**Cellulose**
48.91	53.62	45.96

Table A3. Yield Percentage of product from waste shells

Yield in grams		
Hemicellulose	**Lignin**	**Cellulose**
87.15762	146.22174	198.3174

$Ex. Yield Hemicellulose\ (g) = 1000 \ast = Shell 1000\ Composition \ast\ 0.1782 \ast 0 \ast .4891\%$
$Conversion = 87.15762$

Table A4. Yield in grams of each shell component from 1 kg of argan nut shells

Product Price (USD/kg)		
XOS	**Lignin**	**CNC**
3.43-7.50	1.08	6.43

Table A5. Product Price of Hemicellulose, Lignin, & Cellulose

Products		
XOS	**Lignin**	**CNC**
87	146	198

Table A6. Number of products from hemicellulose, lignin, & cellulose. *Rounded from yield in grams*

Annual Costs $USD		19590
Water	**Electricity**	**Steam**
600	18750	240

$Water = Annual\ Production\ in\ tons * 3 * 2$

$Electricity = Annual\ Production\ in\ tons * 2.5 * 75$

$Steam = Annual\ Production\ in\ tons * 0.3 * 80$

Table A7. Annual energy costs for production

Assumed 20% Yield Reduction		
Hemicellulose	*Lignin*	*Cellulose*
51.51762	91.68174	112.0174
Revenue $USD/kg		
0.1767054366	0.0990162792	0.720271882
Total $USD/kg	0.9959935978	1.205670311
Total $USD/ton	903.550452	1093.766021
Total $USD/100t	90355.0452	109376.6021
Profit $USD	70765.0452	90882.29409

% Conversion was reduced by 20% for all.

*Ex. Hemicellulose=1000*0.1782*0.2891=51.51762*
*Lignin Revenue=Product Price*Yield(g)/1000=1.08*91.68174/1000=0.0990*
Total $USD/kg=sum of Revenue for each component
*Total $USD/ton =0.9959*907.185=903.550*
*Total $USD/100 tons=903.550*100=90,355*
Profit $USD=Total $USD/100 tons-Annual Costs=90,355-19,590=70,765

Table A8. Potential profit of elements of nut shell with 20% yield reduction

Assumed 20% Yield Reduction + % Cost Diff.		
64888	83910	

% Conversion was reduced by 20% for all and operating costs were increased by 30%.

*Ex. Water = Annual production in tons*3*2****1.3***
*Electricity = Annual production in tons*2.5*75****1.3***
*Steam = Annual production in tons*0.03*80****1.3***
Total Cost= 25,467
Total $USD/100 tons-Total Cost= Assumed 20% Yield reduction + 30% operating cost increase = $64,888 - $83,910

Table A9. 20% Yield Reduction + 30% Increase in Annual Operating Costs

Assumed 20% Yield Reduction + % Cost Diff. + MSP Variation			
37781.53164	51096.62149		

% Conversion was reduced by 20% for all , operating costs were increased by 30%, and selling price of products was decreased by 30%.

Ex. Product Prices are all multiplied by ***0.7****.*

Table A10. 20% Yield Reduction + 30% Increase in Annual Operating Costs + 30% Decrease in Product Price

% Price Diff.	XOS1	XOS2	Lignin	CNC

0.7	2.401	5.25	0.756	4.501

Revenue is calculated in the same manner with new price values.

Table A11. Revenue for each product at 70% of market price

Cellulose Extraction

Procedure

Figure A1: Setup of cellulose extraction using an ice bath at -6C to cool NaOH solution containing crushed argan nuts.

Appendix B

Wood Plastic Composites

Formation

Argan Nut Shells were smashed with a hammer, this was done for raw, boiled, and baked shells.

Figure B1: Nut shells boiling in water

Polypropylene was melted in the oven, the shells were added to it and mixed.

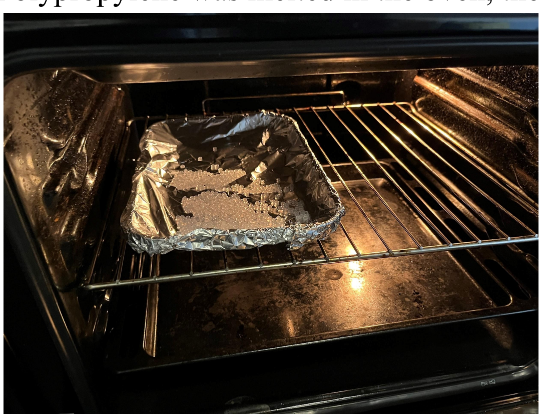

Figure B2: Polypropylene cooking in the oven

Figure B3: Mixing PP and broken down nut shells

Figure B4: WPC post mixing

The mixture was added to a candle mold to take shape.

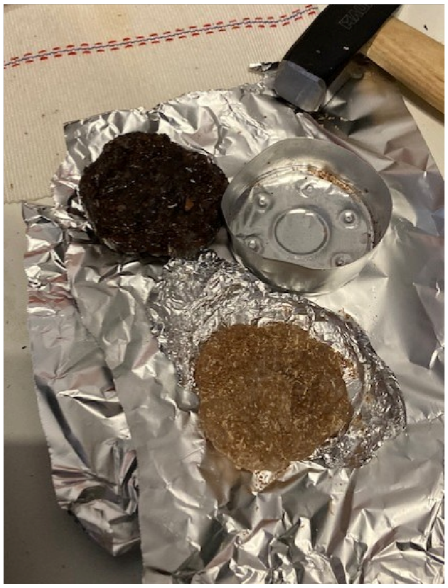

Figure B5: WPC after forming to candle mold shape

Materials Tests

The composites were scratched and a nail and hammer was used to puncture them

The composites were ran under water, process repeated

Figure B6: WPCs being run under water

The composites were soaked in water in three ten minute intervals, side for testing was down.

Figure B7: WPCs soaking in a bowl of water

Cost-Benefit

The cost of 25kg of PP was 81 Euros*1.09 (Conversion Rate)= $88 USD

$88 USD / (25kg/(907kg/ton))=$3,200 USD/ton PP*400 ton PP= $1.3*10^6$ USD/yr

Density of PP=.0009 kg/cm^3

Density of Argan shells=.000596 kg/cm^3

Average Density of Wood= .00059 kg/cm^3

Density of 80:20 Composite= .0009kg/cm^3*.8+.000596*.2=.00084 kg/cm^3

Avg weight of Wood Table=25kg

Volume of WPC= 500 tons*907 kg/ton/(.00084 kg/cm^3)=5.4*10^8 cm^3

Volume of Wood Table= 25kg/(.0009 kg/cm^3)=42,000 cm^3

Number of WPC produced= 5.4*10^8 cm^3/42,000 cm^3= 13,000 tables

Low Price of a WPC Table= $250 USD

$250 USD/Table* 13,000 Tables= $3.2*10^6$ USD Revenue

Cost of Five Workers= $15 USD/hr*40 hr/week*52 weeks/yr*5 workers= $150,000 USD/yr for 5 workers

Double for benefits= $300,000 USD/yr on workers

Profit= $3.2*10^6$ USD/yr from tables-$300,000 USD/yr on workers- $1.3*10^6$USD/yr on PP= $1.6*