COCONUT COIR AS A VERTICAL TEXTILE IN SOILLESS GROWTH SYSTEMS

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by

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ABSTRACT

Coconut coir is an inert fibrous material found between the hard, internal shell and the outer coat of a coconut and is considered a waste-product of the coconut oil industry. Because of the global demand for sustainable, renewable, and reusable products, coconut coir has risen as a natural alternative in many markets. With its high-water absorption, lignin content, density, bending capacity, and neutral pH, coconut coir has become an ideal alternative for soilless growing media. However, it remains unstudied in vertical systems, where less space, energy use, and water consumption are prevalent.

This thesis posits that coconut coir can be used as a vertical farming textile to promote curly cress microgreens growth. This study seeks to identify the use of coconut coir as a reusable media to encourage food production and sustainable architecture. Implementing reusable waste-products like coconut coir into architectural design may provide an impact on design materials and the way designers integrate sustainability. Considering food production as an architectural application may provide designers with opportunities to economically strengthen cities' food accessibility and diversity while supporting a mission for sustainability.

This study utilizes an experimental approach through growth trials for two commercial brands of coconut coir mats to provide data about the germination and treatment of curly cress microgreens in a vertical system. The analysis revealed data that involved mat types, treatment manipulations, and trial repetition. The research was conducted for four successive trials, with two different mat brands, and three different treatments per brand. The research found that curly cress microgreens have the potential to grow on soilless coconut coir media. The study also concluded that germination may be further increased without surface manipulation or an additional adhesive.

The study further investigated the efficacy of coconut coir as a knitted media textile in an architectural application on a lightweight deployable structure. The impact of the lightweight growing structure may play a role in food scarcity and the incorporation of agriculture in architecture. Woven and knit coconut coir media textiles were designed and tested for their ability to support growth of microgreens vertically. The study found that curly cress microgreens have the potential to grow on both woven and knit coconut coir textiles. A 5:1 scaled prototype of a possible architectural application was physically modeled to test the feasibility of the knit media textiles deployment.

Keywords:
coconut coir, media textile, soilless system, microgreens, architecture, sustainability

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CHAPTER 1: INTRODUCTION

1.1 Background

According to the 2019 Global Health Index, “multiple countries have higher hunger levels now than in 2010, and approximately 45 countries will fail to achieve low levels of hunger by 2030” (Grebmer et al., 2019). Enhancing agricultural productivity is necessary, and food production will need to be doubled by the year 2050. Growing food within cities at the doorstep of the consumers eliminates the need for transport and reduces greenhouse gas emissions. For these reasons, vertical farming is growing in research and development.

Vertical farming is the growth of plants, especially edible ones, on a vertical surface to reduce the necessary area for the desired amount of food (Helberg et al., 2019). These systems often incorporate soilless farming techniques such as hydroponics, aquaponics, and aeroponics to increase plant growth while decreasing resource use. In the urban environment, vertical farming with a water-based system can be implemented on a variety of scales from a single-family home to an entire skyscraper (Januszkiewicz, 2017).

Many manufactured soils are not sustainable and exhaust easily over time and use. The need for a sustainable, reusable, durable, and economical option is necessary for alternative farming applications and disaster relief. Organic material such as jute, hemp, cotton, and coconut coir have the capacity to sustain soilless growth. These materials have similar characteristics to standard fibers and yarns which can be developed into textiles. Soilless substrates, in particular, have limited literature about their potential use in germination treatments, repeated use, and deployable structures for vertical farming.

1.1.1 Coconut Coir

Coconut coir is an inert fibrous material found between the hard, internal shell and the outer coat of a coconut and is considered a waste-product of the coconut oil industry. Natural fiber is defined as fibrous plant material produced because of photosynthesis. There are two general classifications of plants producing natural fibers: primary and secondary. Primary plants are those grown for their fiber content, while secondary plants are those where the fibers develop as a by-product from some other primary application. Coir is considered a secondary fiber because it is an industry waste product (Pickering, 2001). The coconut fibers are obtained from the mesocarp of coconut shells and form 30% of the entire fruit (Figure 1.1-1.2) (Salah, 2017). The coconut fibers can be manufactured into many different forms with the most common commercially sourced products being coir pith/peat, coconut fiber, and coconut chips.

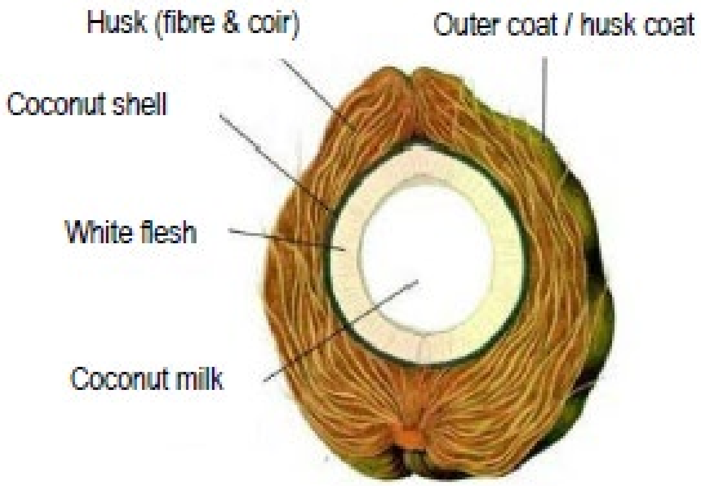


Figure 1.1: Coconut components (Apse, 2016)

Figure 1.2: Coconut husk, fiber, and pith (Greer, 2008)

The husks are normally left on the fields in large mounds as a mulch or used as a fertilizer because of the high potash (potassium-rich salt) content (Figure 1.3). While coconut shells can be used as fertilizer, an extreme number are discarded as waste because of their abundance. The lack of specific regulations for managing coconut waste hinders the proper collection and allocation of this material for industrial exploitation and causes significant environmental problems. This can be seen in India, which has emerged as the largest producer of coconut in the world. Coconut shells represent more than 60% of the domestic waste volume and present serious disposal problems for the local environment (Gunasekaran, 2017). Since coconuts are an organic product, the shell deteriorates easily, which attracts disease vectors such as flies, mosquitoes, cockroaches, and rats. This can cause several problems to human health. Improper management of waste may also favor the emergence of disease such as cholera and dengue, due to their potential of blocking public drainage pathways (Becker, 2016).

Figure 1.3 Coconut shell mound as waste at some oil mills (Gunasekaran, 2017)

Because of its ability to withstand high temperatures, high bending capacity, and low burning, wasted coconut shells have the potential to manufacture plywood, synthetic resin glues, mosquito coils, activated carbon, textile fibers, moldings, concrete aggregates, and abrasives (Gunasekaran, 2017). In addition to the many uses stated, coconut coir also has the potential for textile creation. Although coconut coir has an elongation of 20% in tension, the fibers are often brittle and lack elasticity. This promotes coconut coir as a developable surface rather than a dynamic form-making material. Coconut fiber has a density of .67-10 g/cm^3 which blends well with the combination of tensile strength of 120-500 Mpa, tensile strain of 20% and a water absorption level of 80-180%. Coconut fiber also has a tremendous property of temperature management and hence exhibits good insulation properties. Coconut fiber also has a natural pH value between 5.5-6.8. Additionally, the structure of coconut fiber does not change for several years due to the high lignin content. This means that coconut fiber can maintain the same structure for 3-4 years (Salah, 2017).

1.1.2 Soilless Media Textiles

Traditional soilless system set-ups include plastic boxes, plastic tubes, grow lights, water and inert substrates that have a single use or exhaust quickly. Some of the most common substrates used in soilless systems are rockwool, lightweight expanded clay aggregate, coco coir, coco chips, perlite, vermiculite, peat moss, lava rock, river rock, and sand. Unlike sand, peat, or rockwool, media textiles can withstand the mechanical stress imposed by the roots growing through them without being modified or destroyed. This allows the textile material to be more sustainable and be reused. Media textiles also offer a broad range of morphological properties including thickness, porosity, rigidity, and bending resistance (Storck, 2019). Soilless media textiles also have the capacity to modify stem orientation because of the porous surface structure. These textiles can also be altered for durability and water retention with the addition of a coating or finish.

Textiles have diverse applications, from garments and home materials to a broad range of technical applications. In developing countries, there has been an increased awareness for sustainability, the environment, and the cost of petroleum-based geosynthetics which has led to research devoted to finding natural substitutes. By replacing synthetic materials with natural fibers, carbon emissions could be further reduced (Kiffle et al., 2017).

Currently there are natural textiles that have been used in erosion control, drainage installations, slope protection, heavy metal containment, blanket drains, and wetland reinforcement (Subaida, 2008). These textiles are often exposed to diverse pH, salinity, moisture, and microbial association conditions. Because of these exposure conditions, coconut coir is often chosen among the various lignocellulosic fibers due to the high lignin content. The lignin in coconut coir accounts for the high rigidity, strength retention, and resistance to microbial degradation in comparison to other natural fibers. Coir also tends to absorb moisture through the fine pores and cracks of the fiber surface. This could lead to a quicker degradation of the material so surface modification of natural textiles has been researched to prevent moisture intake and extend its useful life. Some of these surface modifications include a mixture of natural and synthetic products like polyurethane, cashew nutshell liquid, and rubber (Sumi, 2018). In agriculture, textiles are often used to protect the plants from harsh environmental conditions, herbivores, insects, and contaminants rather than initiating germination and growth (Böttjer, 2019). The reliability and sustainability of the textile products make it a viable resource for agricultural use.

Textiles, whether natural or synthetic, have been used in agriculture in various protective applications but little has been investigated about their potential as germination and growth promoters. Natural textiles have the potential to diversify agricultural growth systems and lower non-biodegradable material waste in our food production. Unfortunately, there is even less research on the utility of textile substrates for the dynamic use of vertical farming (Ehrmann, 2019). This study would further the knowledge of coconut coir mats and textiles for the use of soilless media growth.

1.2 Research Approach

A series of treatments were applied to two commercial coconut coir mats in a soilless system to complete a quantitative study consisting of mixed research experiments and observations. Three 5-inch by 5-inch (12.7 x 12.7 centimeters) samples of three different treatments were applied to each of the two brands of coconut coir mats in the same testing environment. This experiment was conducted four times on the same eighteen mats to test the germination rate, health, and adherence of microgreen seeds to the commercial coconut coir mats. The study documented the growth, degradation, and reusability of the two brands of coconut coir mats. These germination studies led to the investigation of a knit and woven textile study for a media textile creation. A 5:1 scale architectural prototype was also investigated as proof of concept.

1.3 Justification and Objective

Coconut coir is a sustainable waste product with the material properties to sustain small plant growth from germination through harvest. When used in a farming system, coconut coir has the potential to transform increasingly dense cities and influence architectural design by orienting future cities around a sustainable food infrastructure. Implementing food producing materials and systems into cities can produce a relationship between urban agriculture and architecture. Because vertical farming systems can be grown on the interior and exterior of architecture with controlled agricultural techniques and materials, the changing climatic conditions have less impact than traditional farming. By combining the programmatic space of architecture and agriculture, there is the potential benefit to gradually repair the land dedicated to farming to its original state. By decreasing land consumption for farming, many parts of the ecosystem damaged by extensive farmlands can be revived by land recovery and regeneration.

By taking initiatives to understand and develop innovative ways to integrate food production and architecture, designers can begin to make long-term sustainable impacts on communities and the environment. Sustainable solutions for food, water, energy, and transport are at the forefront of every city’s concern. Urban agriculture is currently considered one of the solutions to climate change adaptation (Bohn, 2011). It can play a significant role in greening the city and improving the urban climate, while stimulating the productive reuse of urban organic waste and reducing the urban energy footprint (Grebmer, 2019). This can be achieved through the lightweight system that soilless farming provides. These lightweight systems can be highly advantageous when static loads restrict the use of heavy soil containers. To further the weight reduction of the system, the growing media can be integrated into the structural system. The lightweight material of coconut coir could provide the needed substrate for soilless systems. Coconut coir has the potential to be knitted into a media textile that achieves two objectives: structural stability and growing substrate. The knit textiles are sustainable, biodegradable, reusable, lightweight, and limit the amount of material waste during production. According to Lovell (2010), the real challenge is to design urban landscapes for a wide range of functions. Agricultural architecture, like vertical farming, could provide enormous co-benefits if it is designed to meet multiple societal and ecological functions.

1.4 Scope

To limit the boundary of the research, a few points about coconut coir and microgreen choices are listed below.

- General Hydroponics CocoTek Coco Mats and Envelor Coir Grow Mats are considered for the germination study.
- Crop selection considers curled cress microgreen seeds.
- Happy House Organic Garden Twine was used for the knit and woven textile creations.

1.5 Structure of the Thesis

This thesis comprises five chapters which are discussed here briefly.

Chapter 1: Chapter one contains information to contextualize the study of coconut coir and the possible applications of the material. It provides background information for the thesis and clarifies the approach and terminology used throughout the document.

Chapter 2: Chapter two focuses on the literature review that frames the objectives of the research as well as provides context for a methodology. The literature review examines the topics of coconut coir mat manipulation, woven textile structures, knit textile structures, and food-grade adhesives for improved seed attachment. The chapter proposes research questions that arise from the literature review and introduces the methodology of the study.

Chapter 3: Chapter three introduces the methodology that arose from the research questions posed in chapter two. The chapter details the germination experiment set up, data collection, and data analysis. This chapter utilizes analytical software to assess the data collected. It also contains relevant procedures and discussion of experiment outcomes.

Chapter 4: Chapter four provides the design process, module prototyping, and observational analysis for the farming pavilion architectural application. This chapter utilizes diagrams and images to present the construction process. It also discusses the potential postulations and discussions resulting from the prototype process.

Chapter 5: Chapter five contains a discussion based on the analysis of the data collected in the experiment and the outcomes of the farming pavilion investigation. It discusses the major conclusions that are drawn and the resulting implications for architectural applications. It also discusses the limitations and conclusions of the study.

1.6 Terminology

Coconut coir (*Cocos nucifera*): an inert waste-product of the coconut oil industry. Coir is the short, tough fibers that are extracted from the inner husk of the coconut.

Curled cress microgreen (*Lepidium sativum*): the shoots of salad vegetables such as arugula, Swiss chard, mustard, beetroot, etc., picked just after the first leaves have developed.

Soilless culture: an artificial means of providing plants with support and a reservoir for nutrients and water (Johnson, 1985).

CHAPTER 2: LITERATURE REVIEW

2.1 Framework

This chapter explores the literature focusing on different textile structures and the applications of coconut coir in various growing systems. It reviews the research related to soilless systems, media textile creation, vertical adhesion techniques, and the applications of coconut coir. The role of the literature review is to present where the current research for coconut coir, media textiles, and vertical farming systems are and how this study could build upon them. A range of projects involving possible textile manipulations, textile patterns, watering techniques, germination starters, and planting sequences were examined. Investigating these projects aided in the development of the thesis questions and the resulting experimental approach.

This chapter also reveals the research gaps in the current literature about the use of coconut coir as a textile material and growing media. The objective of this chapter is to identify the gaps in literature on coconut coir and its uses in soilless media textile design to create targeted questions for experimental investigation. From these literature gaps, research questions and design solutions were developed for nontraditional applications of coconut coir within the architectural textile industry and urban food production.

2.2 Pocketed Textile Structure

A pocket in a textile structure allows a plant to grow vertically without the need of a secondary material or added adhesive. The pocket also creates an appropriate thermal environment similar to horizontal planting.

A system that implements the use of a pocket is the “Vertical Greenery Modular System” (VGMS). The VGMS is a full-scale prototype on the rooftop of the Energy Department of Politecnico de Turin in Torino, Italy (Bianco, 2017) that implements coconut coir as both media and structure for the growth of green wall plants. The experiment investigated the influence of different plant species and media on the thermal behavior of the module. This project applies a pocketing system to house two different species of plants common to vertical growth: *Lonicera nitida L.* and *Bergenia cordifolia L.* The pocket is constructed by clamping a thin coconut coir mat to the 40 x 50-centimeter (15.75 x 19.69 inches) aluminum frame and cutting an opening in the center (Figure 2.1). The aluminum frame clamps each of the vertical coconut pocketed panels at the edges to provide enough tension to prevent the plants and media from sagging or falling out of the pockets. Once the system is constructed, the pockets are filled with either coconut coir or a mixture of coconut coir/felt soilless media to host a single plant.

Figure 2.1: VGMS pocket with plants (Bianco et al. 2017)

This study implements coconut coir in two uses; one as the growing media and the other as the vertical matting to create the pockets. The loose coconut coir media promotes the growth of the plant while the fronting coconut coir mat acts as structure, thermal insulation, and water retention for the whole system. An automatic irrigation network provided water and nutrients to the modules every two hours for two minutes at the time (Figure 2.2). For each of the plants the number of leaves (L), mean leaf area (LA), and the leaf area index for one module (LAI_m) were calculated to measure the substrate's effect on each of the plant types. The plant *B. cordifolia* grew better in the coconut coir media with a total number of leaves at 134, mean leaf area of 934 x 10^3 mm^3, and a leaf area index of 4.67. The plant *L. nitida* had greater success in the coconut coir/felt substrate with a total number of leaves at 4720, mean leaf area of 392 x 10^3 mm^3, and a leaf area index of 1.96. The coconut coir media was found to be adequate for the growth of the two designated plants but the addition of the felt for *L. nitida* resulted in better growth for that specific plant.

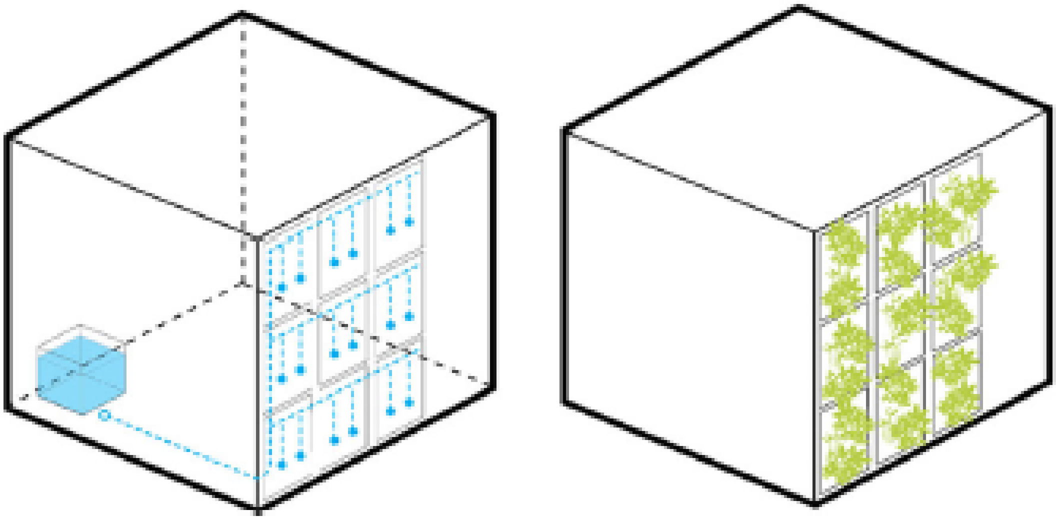


Figure 2.2: Schematic view of the test cells, irrigation system and green modules (Bianco et. al. 2017)

This study led to significant conclusions about media attributes, structural approaches, and system reuse for multiple growth cycles. The VGMS system demonstrated that coconut coir has the ability to provide a structural pocket to hold loose coconut coir media and a mature plant. One of the logistical challenges of the VGMS study is developing a system that supports seed growth from germination through harvest rather than installing mature plants into the pocket. The seeds would need to grow through the mat to receive light or lay as a thin layer on the top of the coconut fiber substrate within the pockets. This leads to the question if a vertical coconut coir mat alone could have the dual ability to create a pocket and support smaller plant growth without additional media? The mat in the VGMS model could maintain structural integrity with a pocket cut and the weight of a plant inside. A possible prototype of a vertical coconut coir mat with multiple pockets for microgreen growth is shown in Figure 2.3. The image depicts two possible scenarios, one of microgreen growth through the opening of the pocket and the second of the microgreens growing through the mat. Both scenarios provide ample support for the shallow root system, but the second allows for a larger available surface area. In these prototypes, the coconut coir mat itself acts as structure and substrate due to the low overall weight and root structure of microgreens.

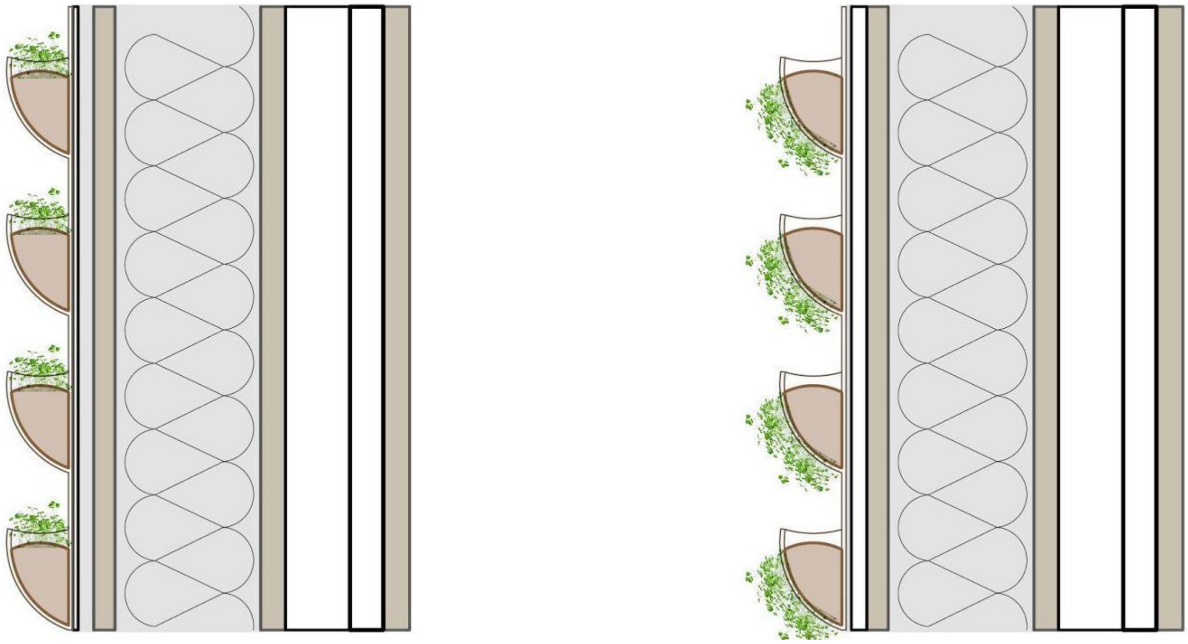


Figure 2.3: Seeding growth in pocket opening (left), seeding growth through pocket material (right)

The VGMS system was studied for an entire year through multiple seasons and environmental conditions. The coconut coir mats in the module were effective in maintaining structural integrity through the variable environmental conditions of temperature and precipitation. This leads to the conclusion that coconut coir is effective in long-term plant hosting in unfavorable conditions. Because of the high durability of coconut coir mats in various climatic conditions, this leads to the question of multiple growth cycles. If the coconut coir can handle changing conditions, can it withstand the planting and removal of multiple plants in the same mat? This could be studied by growing multiple plant cycles on the same coconut coir mat to record degradation and possible exhaustion. The VGMS project outcomes encourage further investigation into the development of simple pocketing for seed growth and harvest while maintaining the integrity of the material structure.

2.3 Woven Textile Structure

Woven textiles are formed by interlacing yarns to form a coherent surface layer. This technique gives a mesh-like appearance with various openings depending on the tightness of the weave. A woven textile provides high tensile strength, high modulus, and low strain, but poor abrasion resistance and dimensional stability (Haghi, 2009). The interlacing yarn pattern of woven textiles offer several advantages including dimensional stability and high packing density (Azrin Hani, 2013). Woven textiles are often created using a process known as beating. This allows in-coming weft yarns to stay close with the other weft yarns in the formation of the textile. This constant back and forth of the weft yarns produces textiles with high porosity but can result in yarn hairiness due to the constant friction. This hairiness can lead to loosened tensioning of the textile if overworked as the yarn begins to unravel.

The research project, *Textiles as Alternative Perspectives for Indoor Gardening* by Svenja Keune, employs a fundamental double-weave structure to create a farming textile. Dynamic circular and elliptical textile patterns (Figure 2.4) are tested to create areas to hold seeds and a cotton growing media.

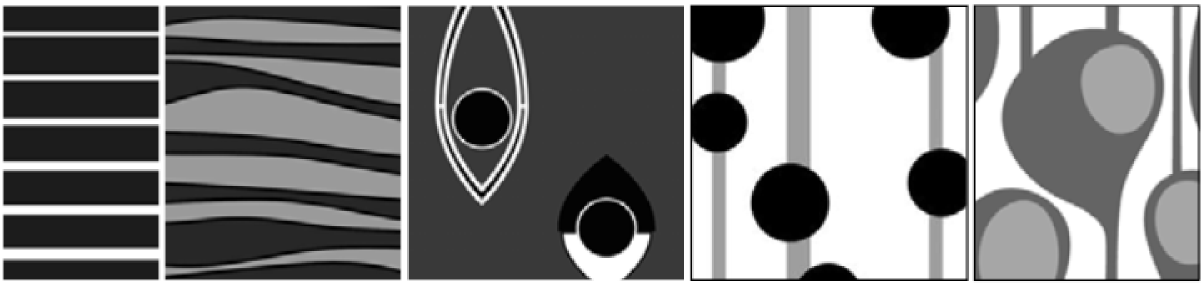


Figure 2.4: Series of pattern designs for circular and elliptical pocket weaves (Keune, 2016)

The robustness of the substrate when inserted into the textile pockets enhances the visual patterning three-dimensionally. The double-weave circles act as a self-supporting pocket structure during the seed germination process, creating a hollow interior for air and light to enter (Figure 2.5). The process promotes alfalfa sprout growth from within the textile.

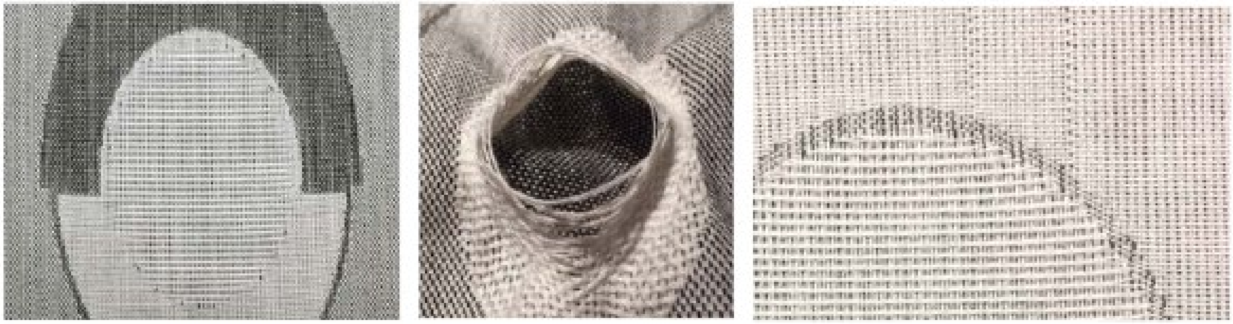


Figure 2.5: Close-up of textile creation and opening for substrate and seeds (Keune, 2016)

The substrate used to grow the alfalfa sprouts is an organic cotton material. To maintain enough moisture in the cotton material, the pieces were sprayed with a water mist by hand. By maintaining a constant moisture in the cotton substrate, the alfalfa sprout growth was visible after one day of activation. By day five of the study, the stems had grown approximately 2-centimeters (0.79 inches) and oriented themselves horizontally towards the light and against gravity (Keune, 2018) (Figure 2.6). This study shows that a woven textile filled with a cotton substrate can host alfalfa sprout growth from germination through harvest.

The study presented in *Textiles as Alternative Perspectives for Indoor Gardening,* introduces conclusions about watering methods, sprout distribution, woven patterning, and user experience. To retain a simple system, the woven textiles and cotton substrates were watered by hand to maintain proper moisture. Watering by hand rather than an irrigation system ensures the seeds have enough water for germination but not an excessive amount that would dislodge the seeds from the textile. Although the conclusion of hand watering promotes increased seed adherence, it could also lead to uneven water collection in the textile. The woven textiles with alfalfa sprout often show more growth and root exposure at the base of the circles where substrate and water collect (Figure 2.6). This could lead to a disproportionate growth of microgreens at the base of a textile sample while the top appears unvegetated.

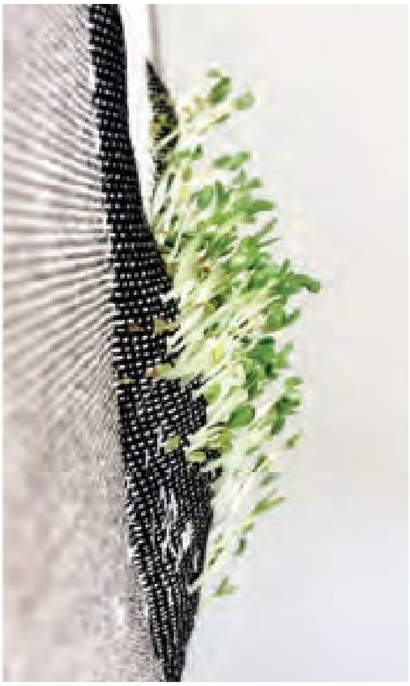


Figure 2.6: Alfalfa sprout growth at base of woven circle (Keune, 2018)

Another conclusion that this study presents is that tight woven patterns do not discourage microgreen growth through the textile. The alfalfa sprouts in this study were able to receive ample light, air, and root space for microgreens to successfully emerge from the cotton substrate. This conclusion ensures that a tight weave pattern, which would be more structurally sound in the vertical orientation, is still porous enough to promote germination and plant growth. This encourages the exploration of various yarn materials and weave patterns for the soilless growth of microgreens.

This study further posits conclusions about the microclimate created when food production is introduced into the human space. This study considers the opportunities of new spatial interactions among plants and people that go beyond simple decoration. This promotes a visceral interaction with food production and a new way of envisioning architectural space creation. This conclusion encourages exploration of media textiles for architectural applications.

The textile in this study was capable of supporting plant growth by allowing water and light to reach the textile surface uniformly. The samples presented in *Textiles as Alternative Perspectives for Indoor Gardening* support the conclusion that double-weave textiles can be crafted into productive soilless media for vertical farming without the need for seed adhesives.

2.3.1 Felted Textile Structure

Felting is the consolidation of fibrous materials by the application of heat, moisture, and mechanical action, causing the interlocking, or matting, of fibers (Britannica, 2016). This technique has grown in attraction for natural fibers such as jute, hemp, and coconut coir because of their relatively low-price points as soil alternatives. Coconut coir has a relatively low tensile strength but has the advantage of stretching beyond its elastic limit without rupturing, which supports the fiber to take up permanent stretch (Nagaraja, 2010). These attributes allow the coconut coir to withstand the demand of the felting process.

To create a felted coconut coir textile, coir fibers of varying length between 5-7.5 centimeters (1.97 – 2.95 inches) are blended together and placed with random orientations to form a mat. The preliminary mat passes through a roller to increase the fiber density between 0.05 and 0.2 g/cm^3 (Bradley, 2010). Once the desired fiber density is achieved, a technique called needle punching is used to bind the fibers into a felted material. Needles repeatedly puncture the mat, creating a tight structure of interlocking coconut coir fibers (Figure 2.7). This technique can result in a variety of mat thicknesses, with the standard between ¼-1 inch (.0635 – 2.54 centimeters).

Figure 2.7: Loose coconut coir fiber (left) and needle punched mat (right) (Bradley, 2010)

To reduce fiber pullout, some mat manufacturers spray a natural rubber polymer latex in order to target structural integration. These felted coconut coir mats are advantageous for soilless media because they are resistant to environmental degradation, not attacked by microbial organisms, resistant to burning, formable, and have flexural rigidity (Bradley, 2010). The felting process for the coconut coir mats ensures that the fibrous makeup is consistent, which helps seeds to grow evenly. The even growth of plants allows for better plant development, ample space for root growth, and less complicated harvest.

Studies have been conducted to test the efficacy of felted coconut coir mats for the germination output of various microgreens. A study on the effects of sowing media on the production of chia microgreens found that seeds sown in coconut coir, or a coconut coir mix, provided the highest germination percentage ranges from 96-98%. The seeds germinated in coconut coir were also found to have the highest microgreen height and fresh weight out of all the media tested (Junpatiw, 2019).

The literature on felted coconut coir textiles encourages further investigation into the effects of coconut coir mats on the germination success of microgreens. The study *Effects of seed preparation, sowing media, seed sowing rate and harvesting period on the production of chia microgreens* presents encouraging data for the use of coconut coir felted mats in the standard tray system for soilless growth. However, little research has been conducted about the use of commercial felted coconut coir mats for vertical soilless systems. Based on this promising data, further research into felted coconut coir mats in vertical systems is needed. Not only does the felting process create flexible textiles, but also durable ones that can be used repeatedly. This encourages studies into the reusability of coconut coir mats as well. Non-woven textiles represent an attractive possibility since they can be widely used in agriculture and building materials industries.

2.4 Knit Textile Structure

Contrary to traditional media like sand, peat, or rockwool, knitted textiles can withstand mechanical stress that is imposed by the roots growing through them without being modified (Storck, 2019). This results in the material being more sustainable than other media because of its durability and longevity. Knit textiles offer a broad range of properties including stitch thickness, porosity, rigidity, and bending resistance based on the knit structure chosen. Knit textiles can be created with the desired dimensions and thickness to stabilize plant roots and maintain proper stem orientation. Not only can the textile properties be tailored but they can also be modified with the addition of a coating or finishing.

Konjac Gum powder is used for vertical farming research in *Influence of Textile and Environmental Parameters on Plant Growth on Vertically Mounted Knitted Fabrics.* The Konjac Gum powder is a polysaccharide known for its high-water binding and gelation abilities commonly used in the food industry. For this study, a single-jersey fabric was knitted on a Silver Reed SK 280 knitting machine with needle gauge E5.6 (i.e., needle distance 4.5mm), using the stitch dimension settings 3, 5, and 7. These parameters were chosen because the fabric's mechanical properties did not change significantly during the study, deeming them reusable. This is a significant factor as a goal for the study was a sustainable setup for vertical farming. All the sample fabrics were seamed to avoid unravelling and then hand-coated with a Konjac Gum power solution (2 grams Konjac Gum Powder dissolved in 240 mL deionized water).

As the seeds begin to germinate and take root in the textile fabric, the Konjac Gum powder slowly dissolves as it is no longer needed. This powder used to glue the seeds to the textile fabric is not water-resistant long term as it begins to swell when exposed to water. The swelling allows for the seeds and roots of the germinating cress seeds to latch onto the textile while also receiving water. The fabric swatches were then mounted on a metal grid and constantly irrigated Figure 2.8).

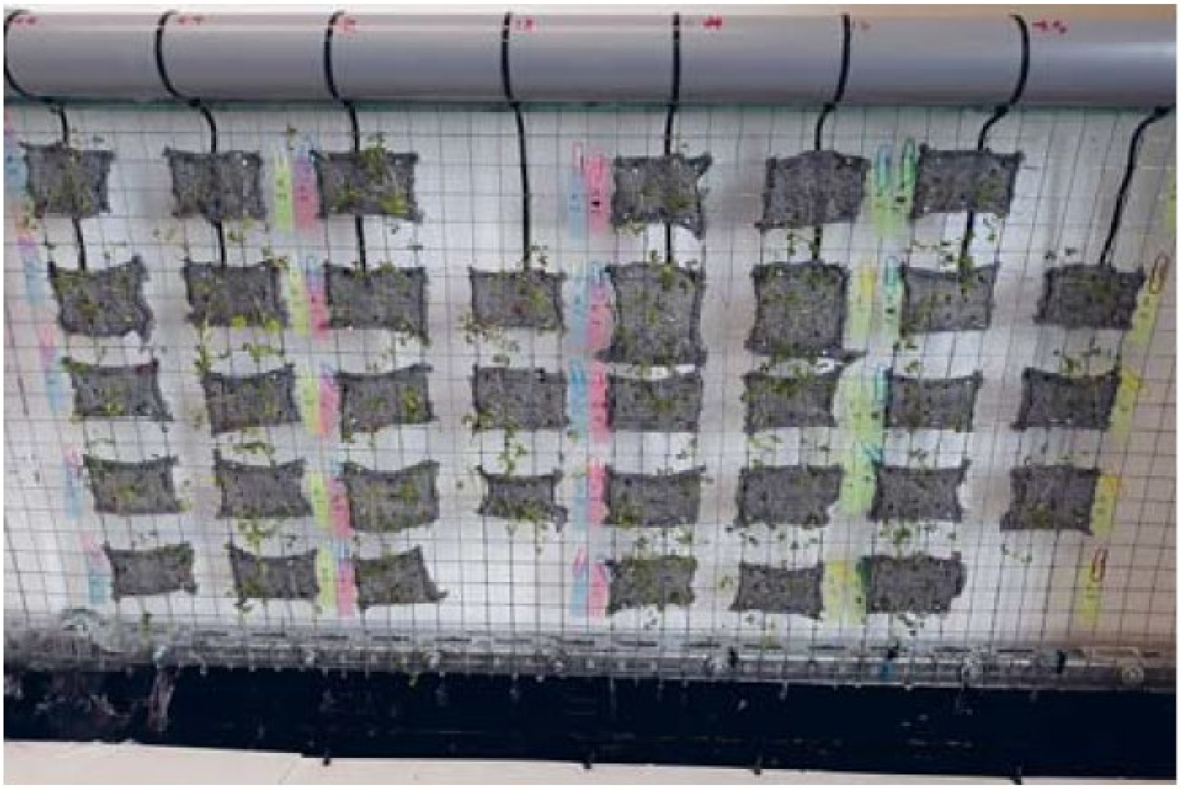


Figure 2.8: Knitted fabric testing arrangement with Konjac Gum and cress seeds (Böttjer, 2019)

The study was found to be successful in growing cress vertically from germination through harvest with the application of a food-grade adhesive. This study introduces a series of conclusions about sustainable reuse, food-grade adhesives, and knit patterns. One of the goals of the knitted fabric study was to create a textile that could endure multiple growth cycles. The study found that at the end of the 27-day trial, the textiles were not altered beyond reuse, stating the potential of multiple growth cycles with a knit textile. Further investigation into the exhaustion point of a knit textile could be useful for the study.

Another conclusion of this study is the application of an adhesive to ensure the seeds have root attachment to the textile. The study does not present data about the germination success of the cress seeds without the Konjac Gum solution for this jersey-knit textile. This leads to the interesting question of if a Konjac Gum powder solution is needed for all vertical soilless media textiles. If so, this study provides a solution recommendation to apply to knit textiles with a mix of 2 grams Konjac Gum Powder dissolved in 240 mL deionized water.

A final conclusion drawn from this study is the possibility of knit patterns to support microgreen growth in the vertical orientation. This study found that the knit pattern was successful in the growth of cress microgreens with the addition of Konjac Gum. A further postulation from this conclusion could be if natural fiber knit textiles perform consistently with the standard jersey material presented in this study. The study mentions that because the application of Konjac Gum worked so well for seed adherence, the stitch dimension for the textile had less effect than previously hypothesized.

Based on this study, a secondary adhesive could improve seed adherence to the textile in vertical farming. When there is no textile manipulation, a seed adhesive can be used to aid in root attachment. This study developed a short-term seed adherence technique by using standard textile machinery and food grade adhesives.

2.5 Research Questions

Coconut coir has been used for various purposes such as furniture, insulation, fertilizer, and soil erosion control. In agriculture, woven and knit textiles are the most common and are typically produced from polyester, polyamide, polyethylene, or other synthetic fibers (Scarlat, 2017). These agricultural textiles are commonly used for soil stability, erosion control, drainage assistance, or pest control yet are rarely biodegradable. Despite the frequent use of textiles in agriculture, there is little literature on textile farming substrates (Ehrmann, 2019). These textile farming substrates can replace exhausted soils, scale down agricultural land use, lower usage of plastics and chemicals in farming, and reduce water and energy consumption (Helberg et al., 2019). Whether its small-scale home growing systems or commercial vertical farming, urban agriculture seems to be benefitting from the exposure to soilless media systems. The benefits of soilless growth systems mixed with sustainable materials suggests a necessity for researchers to investigate further the effects of coconut coir on vertical soilless media textiles. While there is mounting research devoted to soilless media alternatives, there is little devoted to coconut coir as a textile substrate. This study addresses this gap to examine implementations of coconut coir in soilless systems and the creation of a sustainable media textile. The following research questions will guide this study to provide a more focused examination of soilless media growth, manipulation, and textile design for architectural applications.

2.5.1 What is the timeline and capacity of soilless growth on a commercially manufactured coconut coir mat comparable to commercial soilless farming timelines?

In traditional commercial soilless farming, solid substrates like rockwool and peat are common for crop production. Rockwool is a suitable material due to its stable structure, high water holding capacity, and moderate porosity (Sonneveld, 1991). Peat is also highly used as a soilless substrate because of its physicochemical and biological properties that are ideal for plant growth (Schmilewski, 2008). However, rockwool is an inorganic material that is hard to degrade, and peat harvesting destroys endangered wetland ecosystems. With the negative environmental impacts of rockwool and peat, coconut coir was investigated as an alternative because of its stable physicochemical and biological properties, good water retention and aeration characteristics, and material abundance. To assess the effectiveness of a substrate, the properties of particle size, water holding capacity, nutrient holding capacity, cation exchange capacity, and nutrient content are all considered (Ao, 2008). Coconut coir substrates tend to have a higher Phosphorus (P), Potassium (K), Sodium (Na), and Chlorine (Cl) content which aid in the growth of plants (Abad et. al, 2002). In a study on tomato production, coconut coir was an effective substrate for soilless plant growth compared to rockwool and peat substrates. The coconut coir showed higher Potassium (K) and Phosphorus (P) uptake, higher total fruit yield, and the effects of the substrate on the tomato quality were not obvious (Xiong, 2017). This study concluded that coconut coir was a comparable substrate based on timeline and capacity of output in relation to rockwool and peat substrates.

Aeroponics and hydroponics are two traditional soilless farming irrigation systems, especially in urban agriculture. Hydroponics production involves the circulation of a nutrient solution through shallow channels in a closed-loop system (Brechner, 1996) while aeroponics is a subgroup of hydroponics where the plants grow by misting nutrient-rich water (AlShrouf, 2017). Both systems do not require fertile land, large amounts of water, or space compared to conventional agriculture systems. Implementing these systems could increase crop productivity towards greater food security. Studies suggest that the city of Cleveland, Ohio could have self-reliance in fruits and vegetables through heavy application of rooftop farming methods (Grewal & Grewal, 2012).

This research will test coconut coir's ability to accommodate vertical microgreen growth over a seven-day period in an aeroponic system. A series of four identical experiments were conducted over four weeks to determine if coconut coir mats have the capability to be reused through multiple cycles. Success was measured by the overall germination rate of each subsequent growth cycle.

2.5.2 How can the commercial coconut coir mat be manipulated for repeated soilless media growth?

The study *Thermal behavior assessment of a novel vertical greenery module system: first results of a long-term monitoring campaign in an outdoor test cell* used a pocketing technique to grow plants in a mat textile. This pocket shape was chosen to hold the plants in the vertical structure while also allowing light to enter from the top. This was a successful technique as the plants were able to reach necessary water and light exposure. The roots contained themselves within the pocket and did not appear to grow through the vertical textile.

A factor that was not considered in the study but would be critical for reusability is how the roots and the removal of the stems affects the coconut coir mat. The plants in the Bianco study were not removed so root removal was not a factor. The removal of the microgreen plants after each cycle could degrade the mat beyond usability. Moreover, repeated use of the same soilless media textile could be depleted to the point that further cycles do not have proper nutrients to grow. Although there have been studies that manipulate coconut coir into a pocket for plant growth, there is limited research into how this affects the mat structure and overall output over multiple growth cycles.

This research will manipulate commercial coconut coir mats by cutting three horizontal slits halfway through the mat creating pockets to observe mat degradation due to plant growth, root removal, and repeated use. The pocketing will be controlled so there is not over manipulation to the mat, causing the slits to go fully through the mat. Too much manipulation to the mat could result in loss of seeds able to germinate, integrity of the mat structure, and interior coconut fiber needed for root depth. Success will be measured in the germination rate of the pocketed mats.

2.5.3 Does the application of a food-grade adhesive improve the growth and output of microgreen growth on vertical coconut coir mats?

The general assumption in this research study is that microgreen seeds will not have the ability to adhere and germinate vertically on coconut coir mats. Based on the study *Influence of Textile and Environmental Parameters on Plant Growth on Vertically Mounted Knitted Fabrics,* 2-grams of Konjac Gum powder was dissolved in 240-milliliters of deionized water to act as a temporary adhesive for the cress seeds. Konjac Gum powder contains konjac glucomannan, a polysaccharide extracted from Amorphophallus konjac with high-water binding and gelation abilities (Zhang, 2019). The Konjac Gum powder mixture and cress seeds were added to the knit fabric and then dried horizontally at room temperature for two hours before being fixed to the vertical stand. The biodegradable Konjac Gum powder swells when in contact with water and slowly dissolves as the microgreen seeds take root. This could be a problem if the coating is dissolved faster than the root of the cress seeds can anchor themselves to the knitted fabric. This study did find that the drying of the Konjac Gum coating before the cress seeds had ample time to adhere to the textile led to a significant fallout of seeds. A possible way to remedy this problem for this current study would be to allow the Konjac Gum powder mixture to dry in the vertical orientation rather than quickly drying the samples prior to hanging. This could lengthen the time that the mixture is wet and the amount of water available to the seeds at the start of germination. The study *Influence of Textile and Environmental Parameters on Plant Growth on Vertically Mounted Knitted Fabrics* stated that the addition of the Konjac Gum powder mixture increased the number of seeds able to adhere to the textile for germination. Although this experiment authenticated Konjac Gum powder's effectiveness in increasing seed adherence in the vertical orientation, there is a lack of knowledge if the mixture aids in the overall growth and output of the microgreens. The study confirmed that there was an increase in ability to adhere to the fabric, but more research is needed to better understand the growth and output.

Given the findings of increased seed adherence, this study will investigate if the addition of a Konjac Gum powder adhesive increases the overall growth and output of microgreen seeds on a vertical coconut coir mat. This study will also test different Konjac Gum powder ratios and application methods to further investigate the possibilities for food-grade adhesives. The study *Influence of Textile and Environmental Parameters on Plant Growth on Vertically Mounted Knitted Fabrics* used 2-grams of powder for 240-milliliters of water, but it would be interesting to see what lowering the amount of powder does to the experiment. The study also placed the seeds on top of the Konjac Gum solution rather than into the mixture. Incorporating the microgreen seeds into the mixture before applying to the vertical textile could be an interesting alteration to the process. Success will be measured by the germination rate of the coconut coir mats with Konjac Gum Powder application.

2.5.4 Can a coconut coir textile support the growth of microgreen plants from germination through harvest on a lightweight structure?

The study *Form-Finding of an Ecological "Green" Wall Using Bending-Active Biotensegrity Structure* investigated the principles for a pre-stressed and self-stabilized green wall using glass fiber reinforced plastic (GFRP) rods to support the aeroponic growth of curly cress and alfalfa microgreens. The structure is composed of pre-stressed tetrahedron modules balanced on two vertices (Figure 2.9). This aggregation patterned form allows for a flexible, self-supporting, and materially efficient structure. The study implements the use of a three-dimensional weaving pattern consisting of either a monofilament or a combination of monofilament and nylon thread. The germination for both the curly cress and alfalfa microgreens ranged between 50% and 84% (Davis-Sikora & Liu, 2017).

Figure 2.9: Bending-active biotensegrity "green" wall concept (Davis-Sikora & Liu, 2017)

Although the study *Form-Finding of an Ecological "Green" Wall Using Bending-Active Biotensegrity Structure* investigated the use of a textile as a soilless media textile, there is still the opportunity to investigate if microgreen seeds can grow on a lightweight structure in a vertical positioning with coconut coir as a media textile. This study will investigate the efficacy of microgreen growth with a knit coconut coir textile on a lightweight structure. The structure will be prototyped with pre-stressed glass fiber reinforced plastic rods, 3D printed connectors, and a knit coconut coir textile. Success will be measured by the ability of the GFRP and coconut coir textile structure to withstand the load of the microgreens through germination.

2.6 Justification for Research

Previous research for coconut coir has been conducted to suggest its use as a growing media however it also has the capability to advance research in alternative media textiles and vertical farming substrates. Applications such as a coconut coir media textile reveal a sustainable quality that is compatible with the mission of soilless farming, but these applications have not been sufficiently studied. By examining the germination success of coconut coir, researchers and designers may be able to introduce more ways to apply the benefits of soilless vertical farming. Implementing coconut coir as a vertical soilless media textile may provide access to food and sustainable materials while decreasing large agricultural landscapes.

A lack of research about the use of coconut coir justifies a greater look into more specific applications that may be effective in media textiles creation. In addition to studying media textiles, there is a need to study the implementation of these textiles in soilless farming systems. These systems should be examined for their sustainability, reusability, and their impact on their surrounding environment. This study seeks to examine the use of coconut coir in the built environment and food production through a series of vertical growth cycles and textile developments.

CHAPTER 3: GERMINATION STUDY

3.1 Introduction

The goal of this study was to determine germination differences occurring between two coconut coir mat brands and the effect of mat manipulation on germination. The two brands of coconut coir commercial mats were chosen for the germination studies to investigate the potential for culinary growth. General Hydroponics CocoTek Coco Mat and Envelor Coir Grow Mat are two market available products made of coconut coir fibers.

For this study, three different treatments were applied to each of the mat brands. These treatments were labeled as straight seed (STR), pocket (POC), and Konjac Gum (GUM). For all 3 of the treatments, 3 samples were tested, resulting in a total of 18 mats in every trial. The straight seed treatment did not manipulate the coconut coir mat surface for the application of curled cress microgreen seeds. The pocket treatment was conducted by cutting three horizontal slits halfway through the mat to create a pocket on the surface. The Konjac Gum treatment was created by mixing ¼-cup of water (56 grams), ¼-ounce (7 grams) of Konjac Gum powder, and the allotted 2,500 microgreen seeds. This created a gel-like mixture that was then spread onto the coconut coir mat surface.

These results were analyzed with the purpose of exploring the efficacy of coconut coir for the repeated growth of curly cress microgreens in a vertical orientation. The straight seed (STR) treatment was found to be the most successful application out of the three attempted with a p-value of 0.0001. The two mat types, CocoTek and Envelor had similar germination rates, but the Envelor mat had a higher response rate for total weight with a p-value of 0.0124. This could result in a higher biomass content when the Envelor mat is used compared to the CocoTek mat. The increase in germination success between trial 1 and trial 4 was a difference of 185%. Trial 1 had a p-value of 0.0001 and an average stem count of 372.222 stems while trial 4 had a p-value of 0.0001 and an average stem count of 1061.389 stems. These results indicate the excellent potential of suitably surface-modified coconut coir mats for repeated use in soilless growth.

3.2 Experimental Set Up

The experimental set up consists of the examination of two mat products across three surface treatments for the germination performance of curly cress (*Lepidium sativum*) in a vertical configuration. Each treatment (mat x surface manipulation) was replicated 3 times per trial and the experiment was run a total of 4 trials. This totaled a sample size of 18 for each trial and 72 for the entire experiment. The 18 samples were labeled, grouped by treatment, and randomly hung inside the tent with clips (Figure 3.1). The examination was carried out under successive trials in a growing tent in Room 023 NEDlab of the College of Architecture and Environmental Design in Kent, Ohio. Room 023 is a temperature, pressure, and humidity-controlled environment with no exposure to natural light. The lab contained a 30-inch by 30-inch by 60-inch (76.2 x 76.2 x 152.4 centimeters) Lighthouse Hydro growing tent, 135-Watt Black Dog LED light (BDmicro-U), and a thermometer/humidity gauge. The tent was monitored twice daily to record and maintain the environmental conditions.

Figure 3.1: Konjac Gum sample labeled and hung inside tent with clips

3.2.1 Mats

The General Hydroponics CocoTek Coco Mat advertises dimensions of 4-feet by 8-feet by ¼-inch (121.92 x 243.84 x 0.635 centimeters) that can be cut to any desired size. The CocoTek mat is 100% organic coconut coir felted textile finished with a natural tree rubber to prevent fiber pullout. The manufacturer of the product does not directly specify that the CocoTek mat is designed for microgreen seed germination but does mention plant roots will grow through and under the mats.

The Envelor Coir Grow Mat advertises dimensions of 10-inch by 20-inch by ½-inch (25.4 x 50.8 x 1.27 centimeters) that can be cut with scissors. Like the CocoTek mat, the Envelor mat is 100 % organic coconut coir fiber felted textile. The Envelor mat does not have a tree rubber finish on the exterior. The manufacturer of the Envelor product advertises that the mats are ideal seed starters for microgreens because of its pH balance, aeration, and moisture retention.

The two mats were chosen because of their different thicknesses and mat finishes as these factors have the potential to affect the germination and mat degradation through the trials. The natural tree rubber on the CocoTek mat could make it harder for the microgreen roots to attach to the mat but could increase the durability of the surface for multiple use. The Envelor mat could increase root attachment but might lead to more fiber pullout without the addition of a rubber finish.

The coconut coir mats were cut into uniform 5-inch by 5-inch squares (25 in^2, 161.29 cm^2) (Figure 3.2). All the mats were weighed to record the dry weight of the coconut coir mats prior to treatment set-up.

Figure 3.2: Unplanted 5-inch x 5-inch Envelor (left) and CocoTek (right) mat samples

3.2.2 Surface Treatment

The two brands of coconut coir mats were each separated into three different treatments (Figure 3.3-3.4). The straight seed treatment (STR) was conducted by laying the mat flat on a table, distributing the curled cress seeds directly onto the mat, and then spraying with water. The pocket treatment (POC) was created by cutting 3 horizontal 4-inch (10.16 centimeters) slits halfway through the mat to produce a pocket for the seeds to be placed. The final treatment, Konjac Gum (GUM), was established by mixing the microgreen seeds with ¼-cup water and ¼-ounce Konjac Gum powder to form a gel that was spread on the mat samples while on a horizontal surface. For each of the three treatments, three identical samples were created to ensure adequate data was collected for the trial. This resulted in a total of 18 square samples being tested each trial.

Figure 3.3: CocoTek samples with straight seed (left), pocket (center), and Konjac Gum (right) treatments

Figure 3.4: Envelor samples with straight seed (left), pocket (center), and Konjac Gum (right) treatments

3.2.3 Curly cress (*Lepidium sativum)*

Curly cress (*Lepidium sativum*) seeds were chosen because they are mucilaginous seeds that form a gel sack when exposed to water, which lowers their water intake during germination.

Therefore, they do not need to be presoaked before germination. Curly cress was also chosen for its short germination (3-4 days) and harvest time (8-12 days). More information about the microgreen selection process and the attributes considered can be found in Appendix A- Curly Cress Microgreens.

Each coconut coir mat received the same number of curly cress microgreen seeds to maintain a consistent number reference for data collection and comparison. 2,500 curly cress seeds were individually counted for each coconut coir sample. Once counted, the seeds were transferred to their designated coconut coir sample. This was conducted for all 18 coconut coir samples for each of the 4 trials completed; resulting in 45,000 microgreen seeds planted each trial set. Once all 18 coconut coir samples had their respective curled cress seed treatment, they were hung vertically with a string and clipped on the interior of the growing tent.

3.2.4 Trials

All the samples were labeled by their coconut coir brand name, treatment type, and sample number for ease of identification inside the tent. A Black Dog LED light was hung from the top of the growing tent to provide light for 12 hours each day as well as a thermometer and humidity reader. The samples remained in the tent for 7 days to achieve full germination. The samples were watered by hand with a spray water bottle twice a day for the duration of 7 days. All the samples were removed from the tent for photo documentation at the end of each day of the experiment trial. The images for each trial can be found in Appendix D-Growth Cycle Images. This process was repeated for a total of 4 trials to obtain an adequate sample size for data analysis.

Trial 1 did experience a small infiltration of mold on select samples of the pocket and Konjac Gum treatments. The mold only occurred in trial 1 but did not completely inhibit microgreen growth. This trial was included into the data set to see if the appearance of mold were a consequence of treatment that could recur. The small amount of mold in trial 1 was not a factor of treatment since it did not appear in any of the subsequent trials and did not inhibit germination so trial one was deemed eligible for data analysis. The inclusion of trial 1 also increased the sample size of the experiment, ultimately increasing the confidence of the study.

3.3 Method

3.3.1 Data Collection

After the seventh day, data was collected for each of the samples and recorded in an excel spreadsheet. The variables that were collected were: total weight of mat with seeds, number of stems, fresh stem weight, mat dry weight, mat saturated weight, average length of stems, relative humidity of tent, temperature of tent, and the germination rate. The tent humidity and temperature were recorded twice a day for each day of the germination trial. The samples were removed from the tent, weighed in their totality, and then carefully separated from the microgreen stems. The collection process consisted of removing each microgreen stem from the mat, counting them as they were detached, recording their average length, and weighing the stems themselves (Figure 3.5). All recorded data for each trial can be found in Appendix B-Germination Study.

Figure 3.5: Counting and measuring microgreens stems (left), microgreens of varying length (right)

When measuring the length of the stems, every tenth stem was recorded to get an average stem length for that sample (Figure 3.6). Once all the stems were removed from the mat and counted, the stems from each individual sample were weighed.

Figure 3.6: Measuring microgreen stems

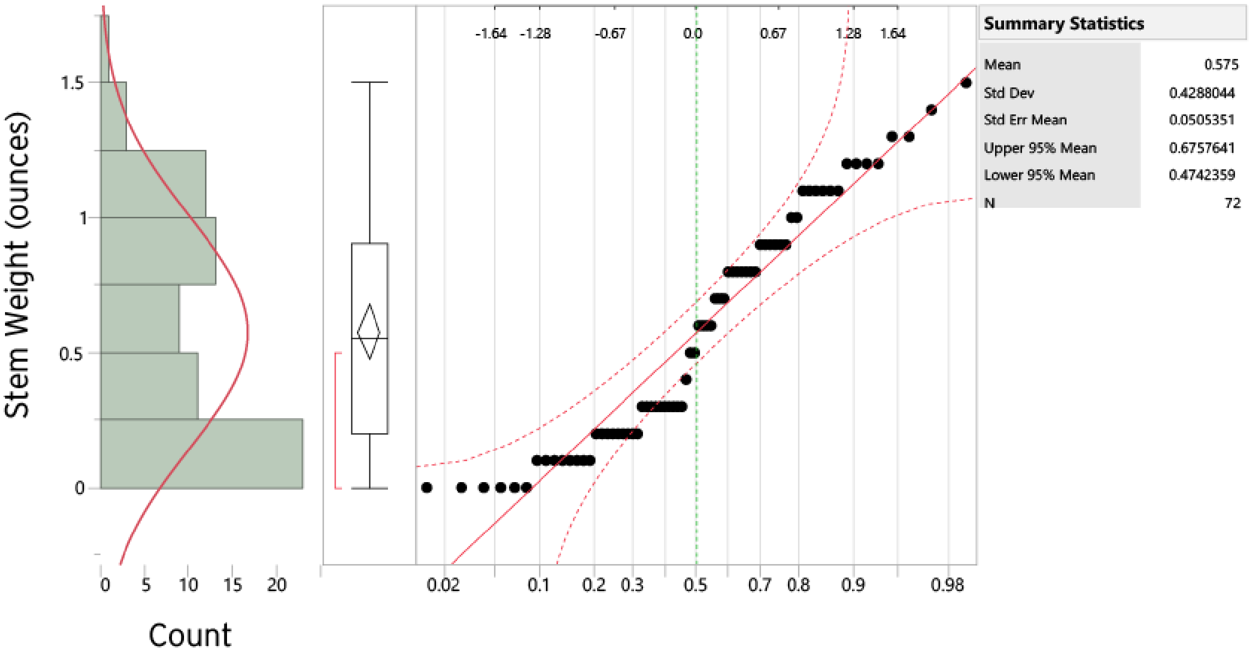
3.4 Data

The following section details the statistical analysis that was performed using the data collected at the end of each trial. The first test conducted was the normal distributions of the raw data to describe how the values of a variable are distributed for all 4 trial experiments. After the normality distributions, correlations tests were conducted to express the extent to which two variables are linearly related without making a statement about cause and effect. The results of the correlations tests were then used to develop fit mixed model analyses for correlation responses with complex covariance structures.

3.4.1 Normal Distribution of Raw Data

The total raw data was assessed for normal distribution in the variables stem weight, stem count, stem length, and total weight (stems and mat) (Figure 3.7-3.10). The data for all 4 trials was combined to test the coconut coir mats through multiple uses. For the combined raw data, the sample size was 72, deeming the total to be large enough to analyze. A fitted normal line was imposed on each of the graphs and a goodness-of-fit test was used to determine if each of the variables were normal. Based on the normality distributions, the variables of stem weight and stem count were deemed not normal while stem length and total weight were normal. The following section examines the analysis of the normal distributions in detail.

Stem weight ranged from 0.0 to 1.5 ounces with a mean of 0.575, a standard deviation of 0.429, and a confidence interval of 95%. Stem weight deviates slightly outside the normal range on the QQ plot indicating a non-normal distribution (Figure 3.7).

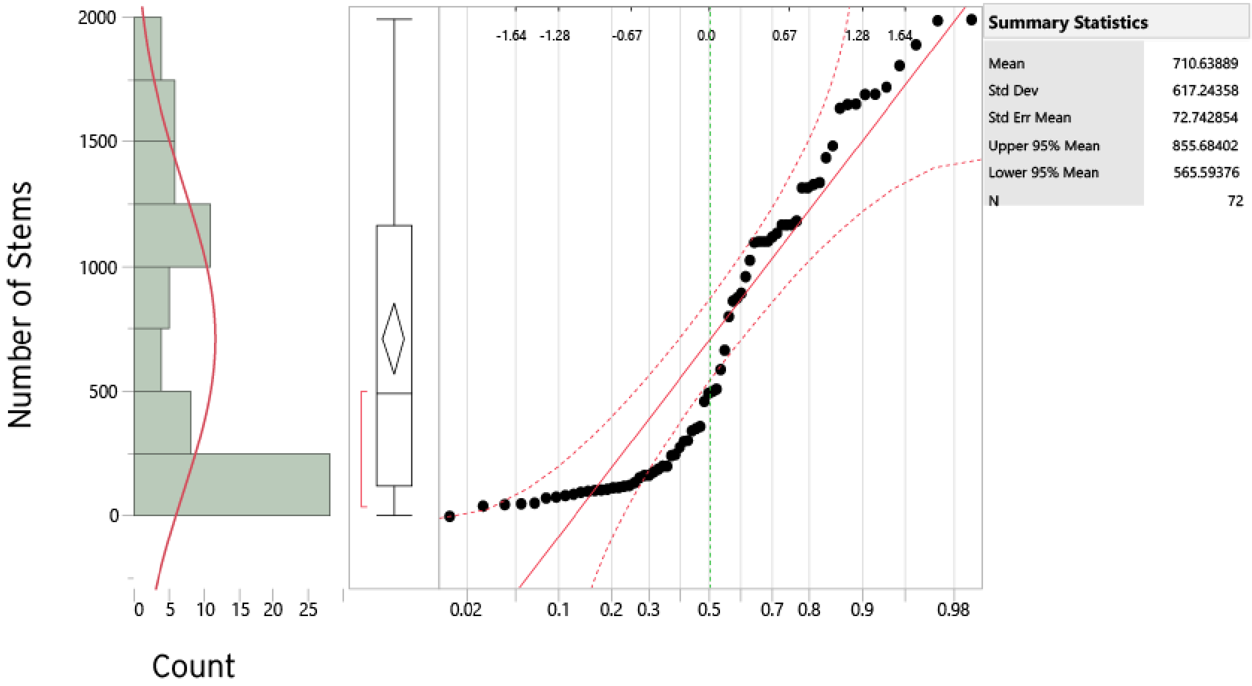


Summary Statistics

Mean	0.575
Std Dev	0.4288044
Std Err Mean	0.0505351
Upper 95% Mean	0.6757641
Lower 95% Mean	0.4742359
N	72

Figure 3.7: Normal distribution for stem weight

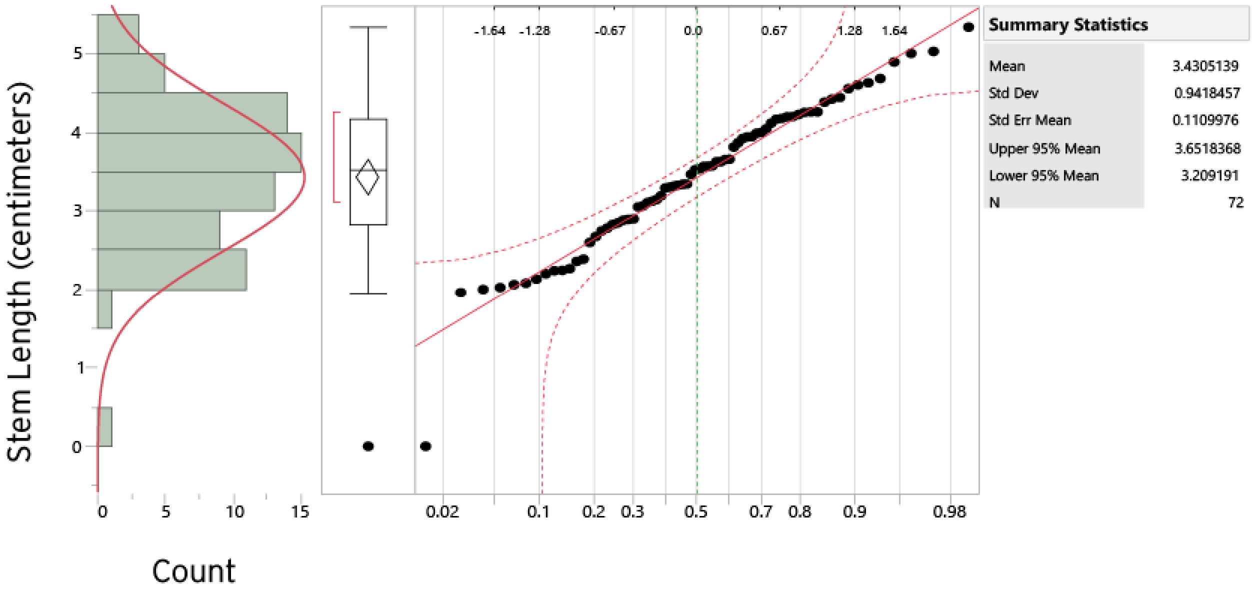
Stem count ranged from 0.0 to 1989 stems with a mean of 710.639, a standard deviation of 617.244, and a confidence interval of 95%. The stem count variable indicates a skewed distribution where the highest number of stem counts are recorded. The QQ plot presented in Figure 3.8, illustrates an increase in stem count as the trial progressed.



Summary Statistics	
Mean	710.63889
Std Dev	617.24358
Std Err Mean	72.742854
Upper 95% Mean	855.68402
Lower 95% Mean	565.59376
N	72

Figure 3.8: Normal distribution for stem count

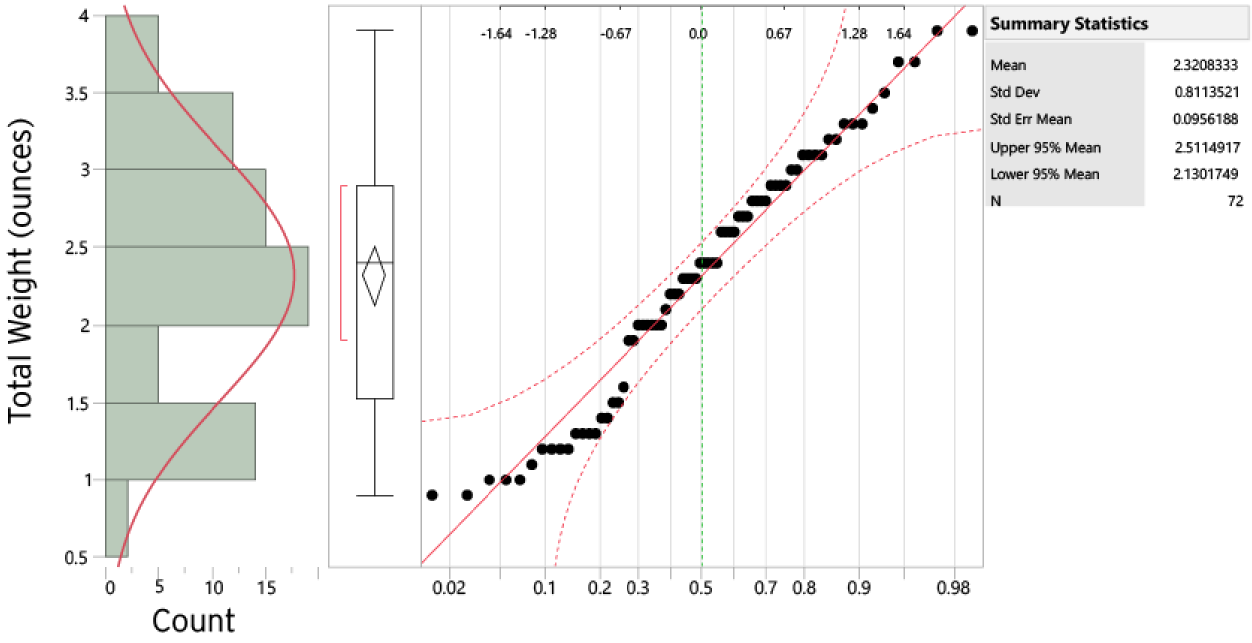
Average stem length ranged from 0.0 to 5.341 centimeters (0 – 2.1 inches) with a mean of 3.431, a standard deviation of 0.942, and a confidence interval of 95%. The histogram and QQ plot for stem length presented in Figure 3.9 follows the normal curve, illustrating the data for stem length to appear normal.



Summary Statistics	
Mean	3.4305139
Std Dev	0.9418457
Std Err Mean	0.1109976
Upper 95% Mean	3.6518368
Lower 95% Mean	3.209191
N	72

Figure 3.9: Normal distribution for average stem length

Total weight ranged from 0.9 to 3.9 ounces with a mean of 2.32, a standard deviation of 0.811, and a confidence interval of 95%. The histogram and QQ plot for total weight presented in Figure 3.10 follows the normal curve, illustrating the data for stem length to appear normal.



Summary Statistics	
Mean	2.3208333
Std Dev	0.8113521
Std Err Mean	0.0956188
Upper 95% Mean	2.5114917
Lower 95% Mean	2.1301749
N	72

Figure 3.10: Normal distribution for total weight

After the presented normality distributions, it was concluded that the data does not require transformation to be examined for predictions and inputs into the following correlations and fit mixed models based on minimal deviations from the normal. The non-normal variables of stem count and total weight were able to be used for the subsequent regression tests because these analyses are robust to the assumption of normality. Because the sample size is above 20, normality is not an issue.

3.4.2 Prediction of the Response Variables

After running the normality distributions, correlation tests were created to find if the variables, trial, mat type, and treatment were significant in impacting stem length, total weight, stem count, and total weight. The correlation analysis indicated that trial had the most significant impact on stem length and stem weight with stem count being the best indicator of trial success. The trial with the strongest positive significance across the variables was trial four. The analysis also indicated that treatment had a significant impact on stem weight and stem count with stem length being the best indicator of treatment success. The treatment with the strongest positive significance across the variables was straight seed. Mat type only exhibited a significant impact on the total weight with Envelor having the stronger positive significance. The following section examines the results of the correlation analysis in detail.

The charts in Figure 3.13 show the correlations for trial, mat, and treatment in response to stem length with values in red and orange that indicate a significant p-value. For this experiment, trial and treatment had a significant effect on the overall stem length. Stem length had an R-squared value of 0.73 which states a strong significance. Trial 2 (Trial [2]) had a p-value of 0.0006 and a t-ratio of -3.62. This illustrated that trial 2 had a strong negative correlation regarding stem length than the other trials indicated by the negative t-ratio value. On the contrary, trial 4 (Trial [4]) had a p-value of 0.0001 and a t-ratio of 6.14. These values represent a strong positive correlation between trial 4 and stem length. The notion that trial 2 and trial 4 are significantly different is validated by the raw data presented in Figure 3.11. This postulates that stem length increases with the repetition of trials.

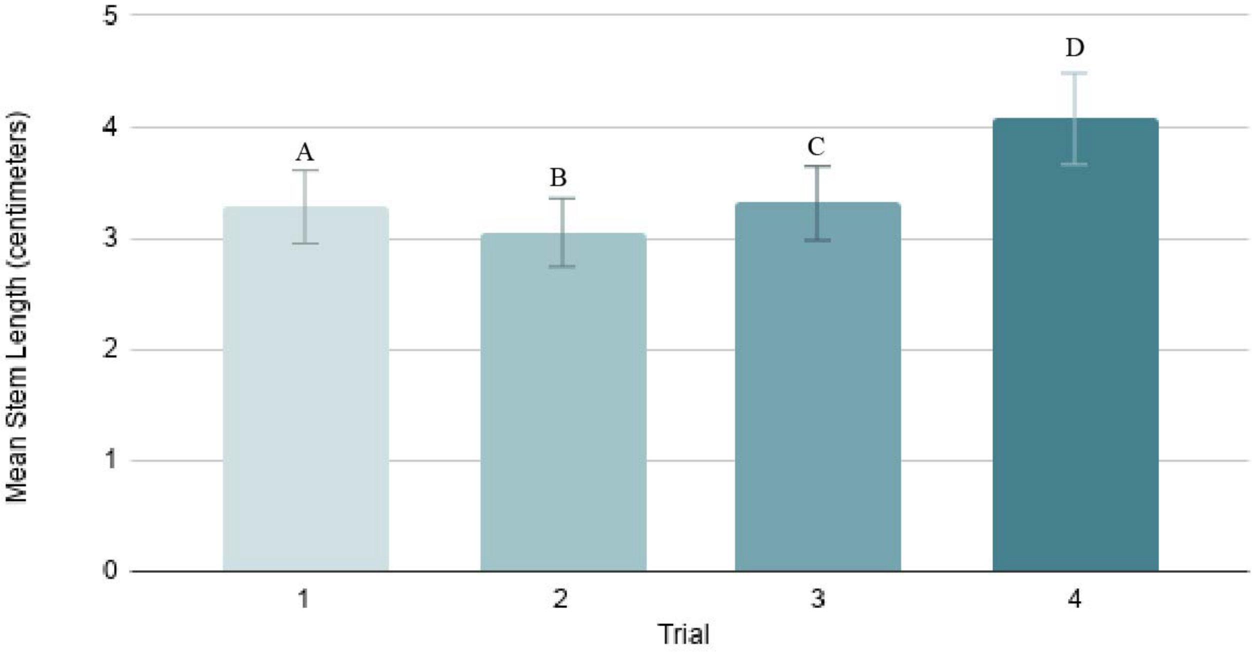


Figure 3.11: Mean stem lengths (centimeters) for ***Trial 1*** *A=3.282 cm (P=0.1595),* ***Trial 2*** *B=3.052 cm (P=0.0006),* ***Trial 3*** *C=3.315 cm (P=0.2753), and* ***Trial 4*** *D=4.073 cm (P=0.0001)*

All 3 of the treatments indicated a significant correlation regarding stem length with straight seed having the highest success. The Konjac Gum treatment (Treatment [GUM]) had a p-value of 0.0001 and a t-ratio of -11.01. This highly negative t-ratio indicates a strong negative correlation between the Konjac Gum treatment and the stem length measurements. The pocket treatment (Treatment [POC]) presented a p-value of 0.0183 and a t-ratio of 2.42. Although this is a positive correlation, it is not as strong as the straight seed treatment. The straight seed treatment (Treatment [STR]) had a p-value of 0.0001 and a t-ratio of 8.59. This large positive t-ratio indicates a strong correlation between the stem length and straight seed treatment. This analysis shows that in relation to promoting stem length, the Konjac Gum treatment was the least applicable while the straight seed treatment had the highest success. This conclusion is corroborated by the raw data in Figure 3.12. The strong p-value and mean length exhibits the straight seed treatment as the most successful in relation to promoting stem length.

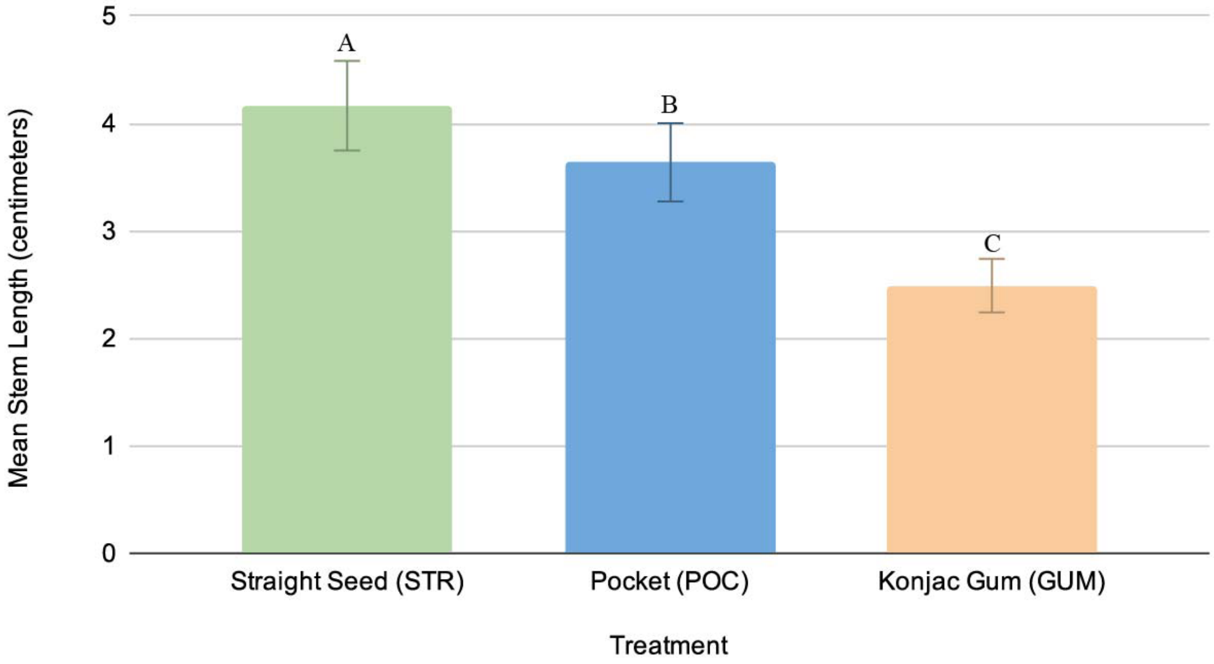
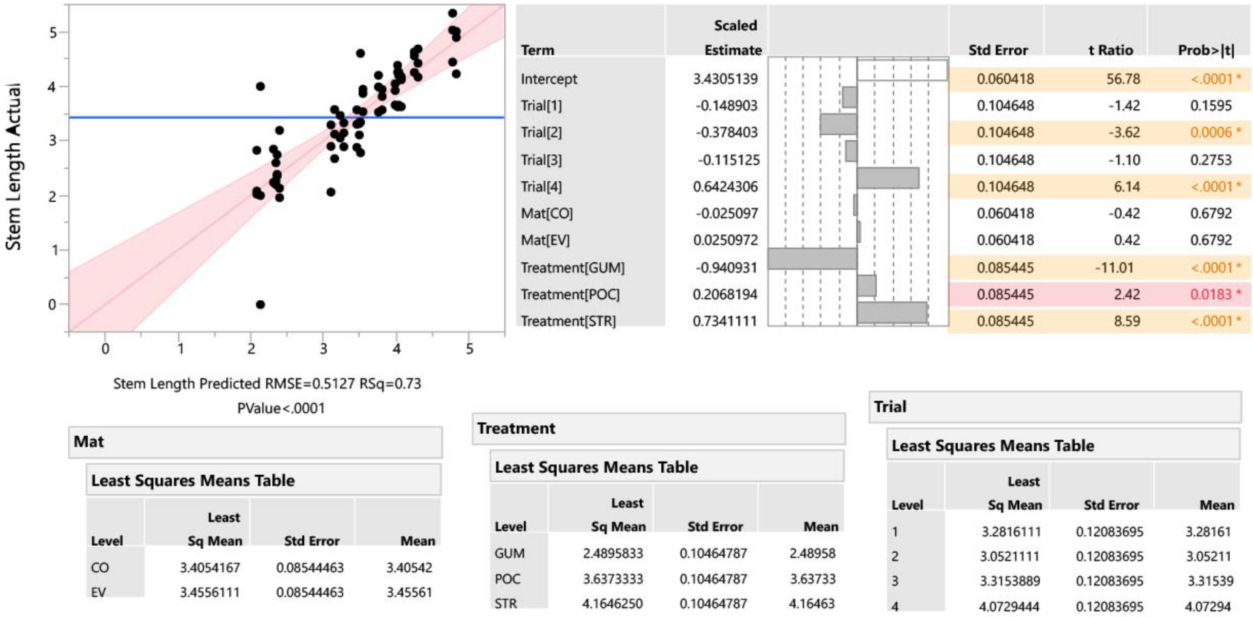


Figure 3.12: Mean stem length (centimeters) for ***straight seed (STR)*** *A=4.165 cm (P=0.0001),* ***pocket (POC)*** *B=3.637 cm (P=0.0183), and* ***Konjac Gum (GUM)*** *C=2.490 cm (P=0.0001)*



Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.4305139	0.060418	56.78	<.0001 *
Trial[1]	-0.148903	0.104648	-1.42	0.1595
Trial[2]	-0.378403	0.104648	-3.62	0.0006 *
Trial[3]	-0.115125	0.104648	-1.10	0.2753
Trial[4]	0.6424306	0.104648	6.14	<.0001 *
Mat[CO]	-0.025097	0.060418	-0.42	0.6792
Mat[EV]	0.0250972	0.060418	0.42	0.6792
Treatment[GUM]	-0.940931	0.085445	-11.01	<.0001 *
Treatment[POC]	0.2068194	0.085445	2.42	0.0183 *
Treatment[STR]	0.7341111	0.085445	8.59	<.0001 *

Mat

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CO	3.4054167	0.08544463	3.40542
EV	3.4556111	0.08544463	3.45561

Treatment

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
GUM	2.4895833	0.10464787	2.48958
POC	3.6373333	0.10464787	3.63733
STR	4.1646250	0.10464787	4.16463

Trial

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
1	3.2816111	0.12083695	3.28161
2	3.0521111	0.12083695	3.05211
3	3.3153889	0.12083695	3.31539
4	4.0729444	0.12083695	4.07294

Figure 3.13: Correlation analysis for stem length

The charts in Figure 3.16 show the correlations for trial, mat, and treatment in response to stem weight with significant p-values highlighted in orange. For this experiment, trial and treatment had a significant effect on the overall stem weight. Stem weight had an R-squared value of 0.54 which states a moderate significance. Trial 1 (Trial [1]) had a p-value of 0.0003 and a t-ratio of -3.83. This negative t-ratio indicates a negative correlation between trial 1 and stem weight. Like it was seen in the analysis for stem length, trial 4 (Trial [4]) has a strong positive correlation. Trial 4 had a p-value of 0.0002 and a t-ratio of 3.93. This indicates a higher recorded stem weight in trial 4 than the other trials. The significant difference found in the correlations for trial 1 and trial 4 are confirmed in the bar chart in Figure 3.14. Trial 4 has a much higher mean stem weight, resulting in a strong positive p-value.

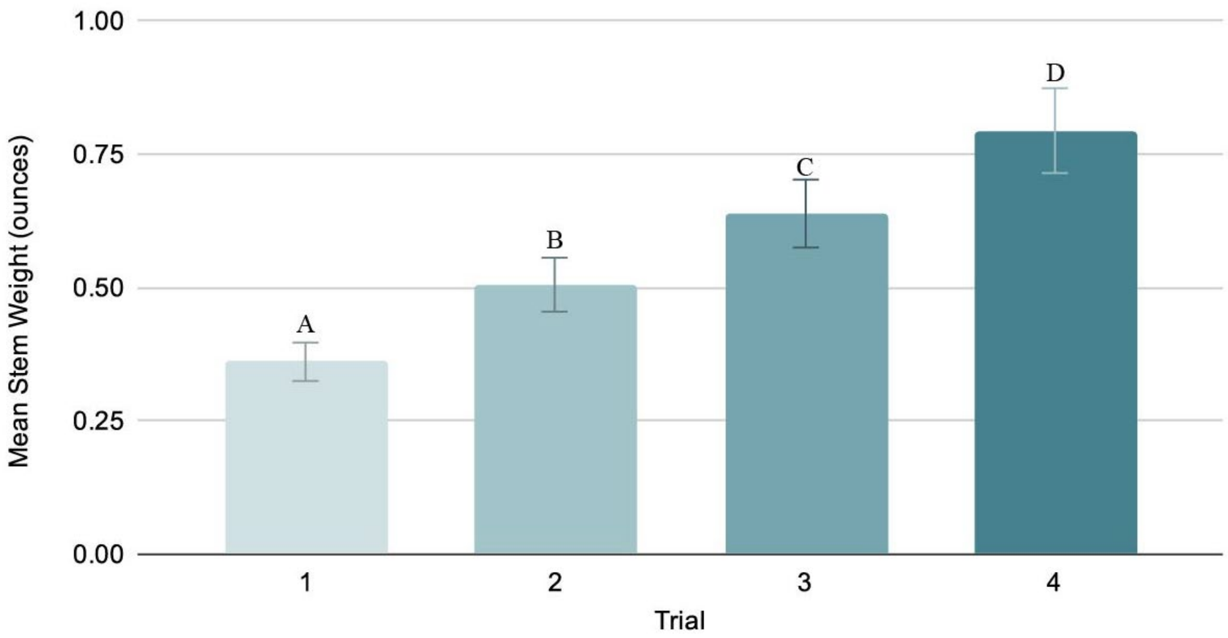


Figure 3.14: Mean stem weight (ounces) for ***Trial 1*** *A=0.0361 ounce (P=0.0003),* ***Trial 2*** *B=0.506 ounce (P=0.2184),* ***Trial 3*** *C=0.639 ounce (P=0.2571),* ***Trial 4*** *D=0.794 ounce (P=0.0002)*

Out of the 3 treatments, Konjac Gum and straight seed showed significant correlations with straight seed having the most success in relation to stem weight. Konjac Gum (Treatment [GUM]) presented a p-value of 0.0001 and a t-ratio of -8.40. This negative t-ratio indicates a negative correlation for the treatment regarding stem weight. Consequently, straight seed had a p-value of 0.0001 and a t-ratio of 7.31. This strong positive correlation indicates that the straight seed treatment was the most successful out of the 3 for stem weight. The conclusion that the straight seed treatment had the most significant impact is confirmed in the raw data presented in Figure 3.15.

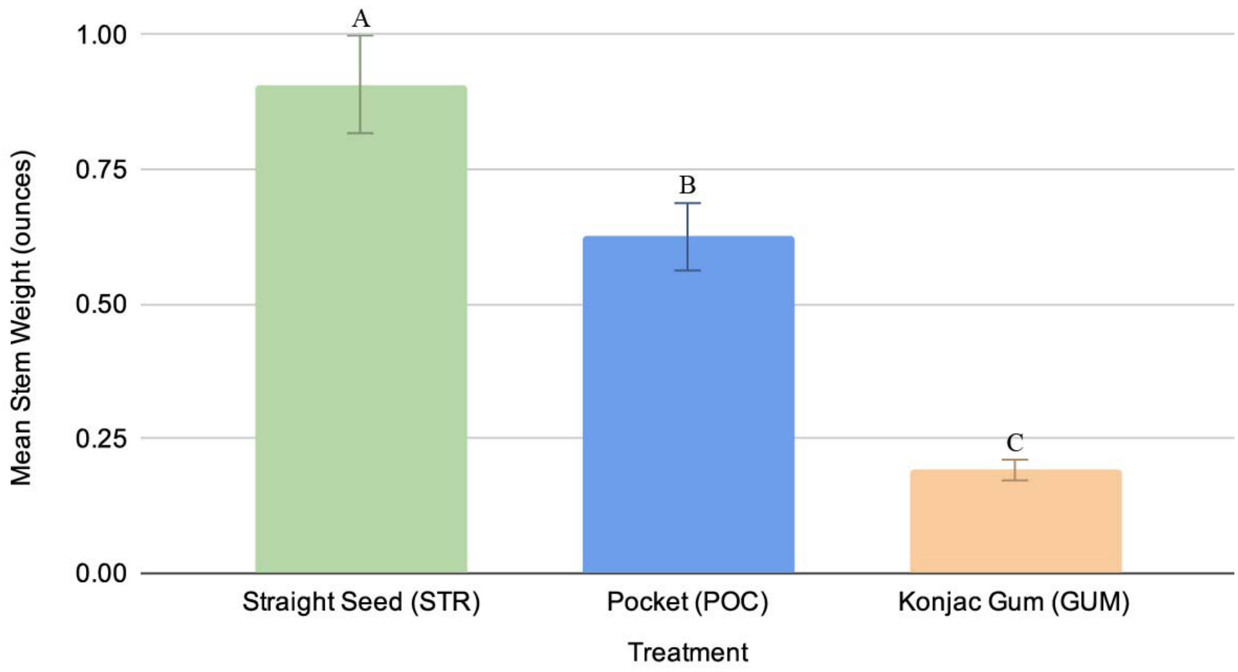
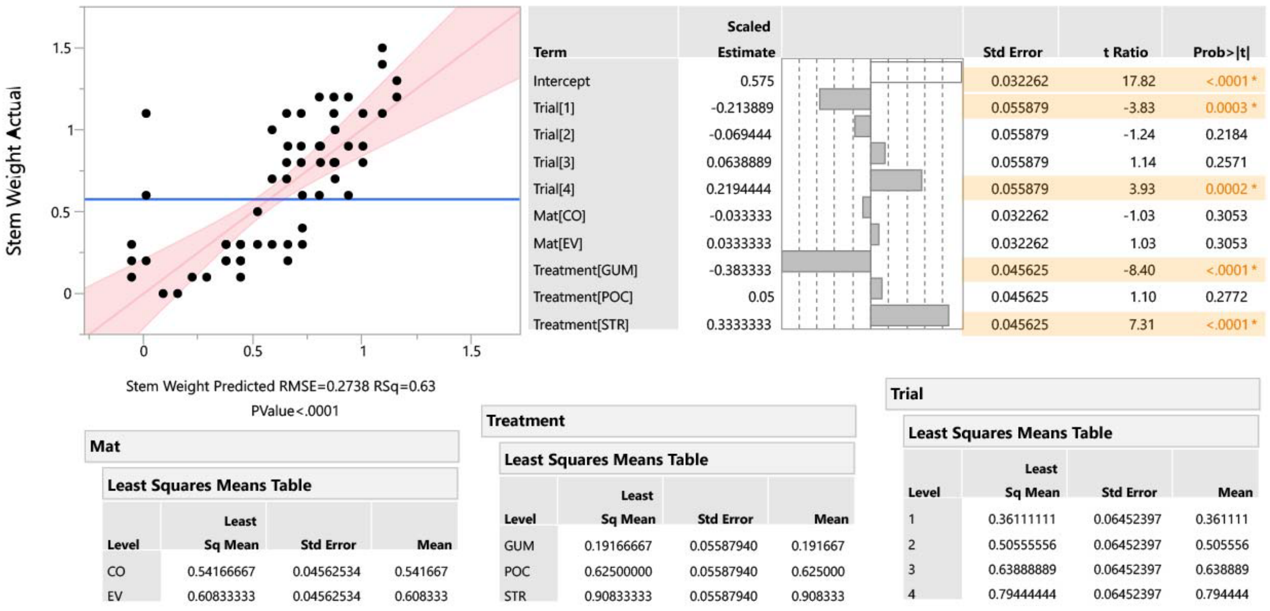


Figure 3.15: Mean stem weight (ounces) for ***straight seed (STR)*** *A=0.9083 ounce (P=0.0001),* ***pocket (POC)*** *B=0.635 ounce (P=0.2772), and* ***Konjac Gum (GUM)*** *C=0.192 ounce (P=0.0001)*



Stem Weight Predicted RMSE=0.2738 RSq=0.63
PValue<.0001

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.575	0.032262	17.82	<.0001 *
Trial[1]	-0.213889	0.055879	-3.83	0.0003 *
Trial[2]	-0.069444	0.055879	-1.24	0.2184
Trial[3]	0.0638889	0.055879	1.14	0.2571
Trial[4]	0.2194444	0.055879	3.93	0.0002 *
Mat[CO]	-0.033333	0.032262	-1.03	0.3053
Mat[EV]	0.0333333	0.032262	1.03	0.3053
Treatment[GUM]	-0.383333	0.045625	-8.40	<.0001 *
Treatment[POC]	0.05	0.045625	1.10	0.2772
Treatment[STR]	0.3333333	0.045625	7.31	<.0001 *

Mat

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CO	0.54166667	0.04562534	0.541667
EV	0.60833333	0.04562534	0.608333

Treatment

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
GUM	0.19166667	0.05587940	0.191667
POC	0.62500000	0.05587940	0.625000
STR	0.90833333	0.05587940	0.908333

Trial

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
1	0.36111111	0.06452397	0.361111
2	0.50555556	0.06452397	0.505556
3	0.63888889	0.06452397	0.638889
4	0.79444444	0.06452397	0.794444

Figure 3.16: Correlation response for stem weight

The charts in Figure 3.19 show the correlations for trial, mat, and treatment in response to stem count with significant p-values highlighted in orange. As was seen in the correlation for stem length and stem weight, trial and treatment had a significant effect on the overall stem count. Stem count had an R-squared value of 0.77 which states a strong significance. Trial 1 (Trial [1]) had a p-value of 0.0001 and a t-ratio of -5.32 while trial 2 (Trial [2]) had a p-value of 0.0022 and a t-ratio of -3.18. Both trials presented a negative correlation regarding stem count, with trial 1 being the lower of the two. On the other hand, trial 3 (Trial [3]) had a p-value of 0.0039 and a t-ratio of 2.99. Although this does present a positive correlation between trial 3 and stem count, it is not as significant of a correlation as presented in trial 4. Trial 4 (Trial [4]) indicated a p-value of 0.0001 and a t-ratio of 10.12. This highly positive t-ratio indicates that trial 4 had the most success regarding stem count out of all the trials. This conclusion is further confirmed by the graph in Figure 3.17. Trial 4 had a significantly higher mean stem count in relation to the other three trials. This leads to the conclusion that an increase in stem count can be expected with repeated trials. A highly positive correlation in trial 4 is consistent with the findings from the previous correlations for stem length and stem weight.

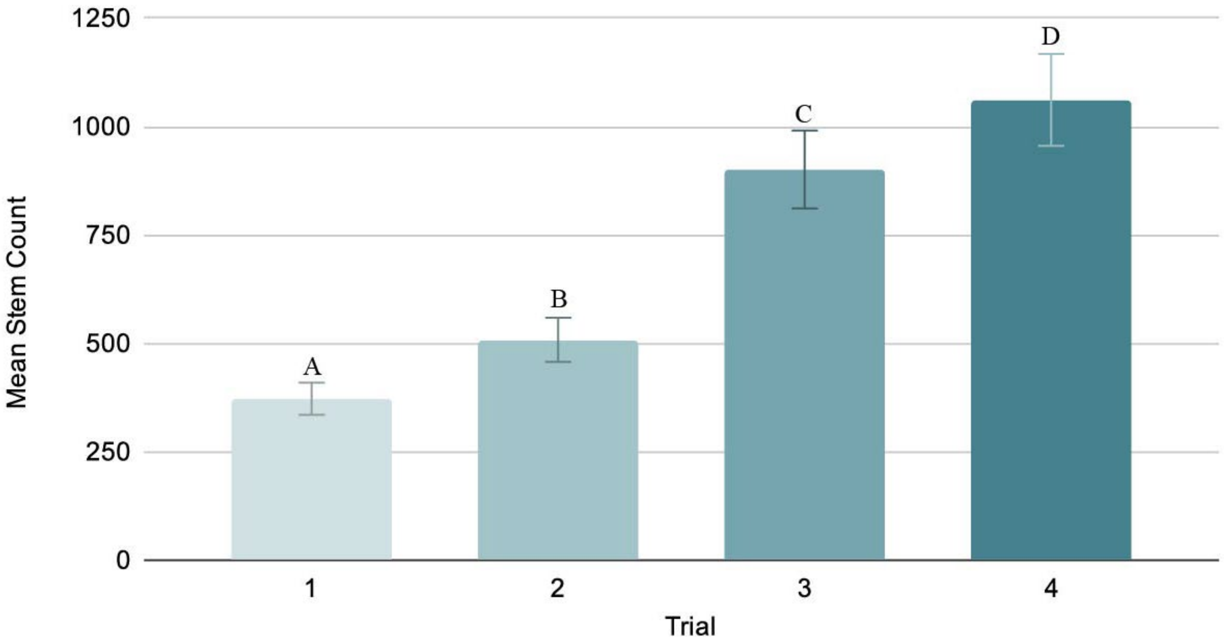


Figure 3.17: Mean stem count for ***Trial 1*** *A=372.2 stems (P=0.0001),* ***Trial 2*** *B=508.1 stems (P=0.0022),* ***Trial 3*** *C=900.9 stems (P=0.0039), and* ***Trial 4*** *D=1061.4 stems (P=0.0001)*

Out of the 3 treatments, Konjac Gum and straight seed showed significant correlations with straight seed having higher success. Konjac Gum (Treatment [GUM]) presented a p-value of 0.0001 and a t-ratio of -11.29. This negative t-ratio indicates a negative correlation for the treatment regarding stem count. Consequently, straight seed had a p-value of 0.0001 and a t-ratio of 10.12. This strong positive correlation indicates that the straight seed treatment was the most successful out of the 3 regarding stem count. The conclusion that the straight seed treatment has the highest significance is confirmed by the stem count success presented in Figure 3.18.

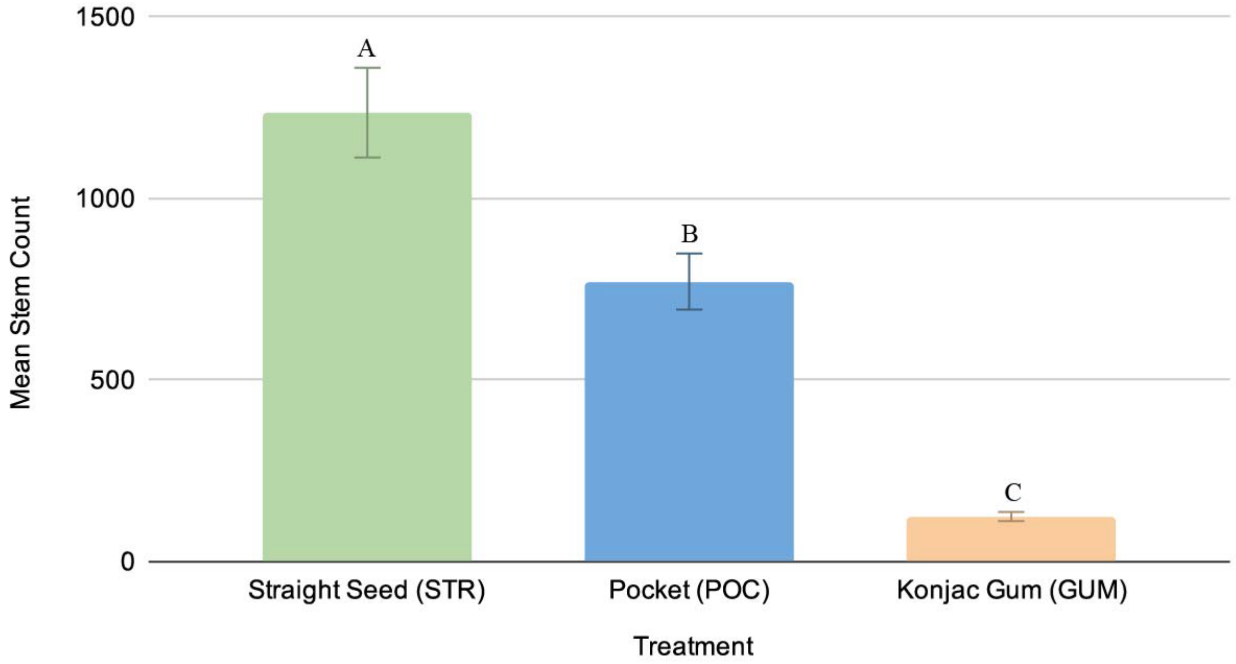
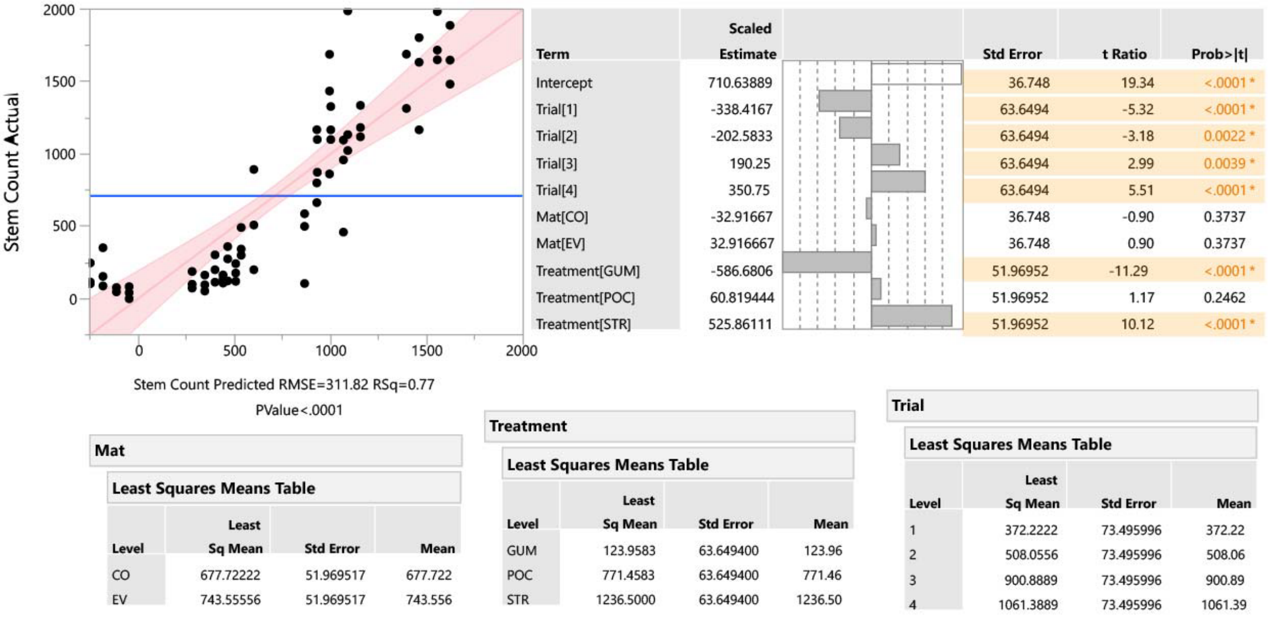


Figure 3.18: Mean stem count for ***straight seed (STR)*** *A=1236.5 stems (P=0.0001),* ***pocket (POC)*** *B=771.5 stems (P=0.2462), and* ***Konjac Gum (GUM)*** *C=123.9 stems (P=0.0001)*



Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	710.63889	36.748	19.34	<.0001*
Trial[1]	-338.4167	63.6494	-5.32	<.0001*
Trial[2]	-202.5833	63.6494	-3.18	0.0022*
Trial[3]	190.25	63.6494	2.99	0.0039*
Trial[4]	350.75	63.6494	5.51	<.0001*
Mat[CO]	-32.91667	36.748	-0.90	0.3737
Mat[EV]	32.916667	36.748	0.90	0.3737
Treatment[GUM]	-586.6806	51.96952	-11.29	<.0001*
Treatment[POC]	60.819444	51.96952	1.17	0.2462
Treatment[STR]	525.86111	51.96952	10.12	<.0001*

Mat

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CO	677.72222	51.969517	677.722
EV	743.55556	51.969517	743.556

Treatment

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
GUM	123.9583	63.649400	123.96
POC	771.4583	63.649400	771.46
STR	1236.5000	63.649400	1236.50

Trial

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
1	372.2222	73.495996	372.22
2	508.0556	73.495996	508.06
3	900.8889	73.495996	900.89
4	1061.3889	73.495996	1061.39

Figure 3.19: Correlation response for stem count

The charts in Figure 3.22 show the correlations for trial, mat, and treatment in response to total weight with significant p-values highlighted in orange and red. Consistent with the correlation for stem length, stem weight, and stem count, trial significant effect on the total weight. However, treatment was not a significant factor for total weight while mat type exhibited significance. Total weight had an R Squared value of 0.54 which states a moderate significance. Trial 1 (Trial [1]) had a p-value of 0.0001 and a t-ratio of -8.16. This value indicates a strong negative correlation between trial 1 and total weight. Trial 2 (Trial [2]) presented a p-value of 0.0001 and a t-ratio of 4.05. Trial 4 (Trial [4]) also indicated a positive correlation with a p-value of 0.0122 and a t-ratio of 2.58. This t-ratio is not as strong as trial 2 but is still consistent with the previous correlations of trial 4 having a strong correlation. The significance in the correlations is corroborated by the graph in Figure 3.20. Trial 2 and trial 4 both register an increase from the previous trials, resulting in a significant difference in mean total weight.

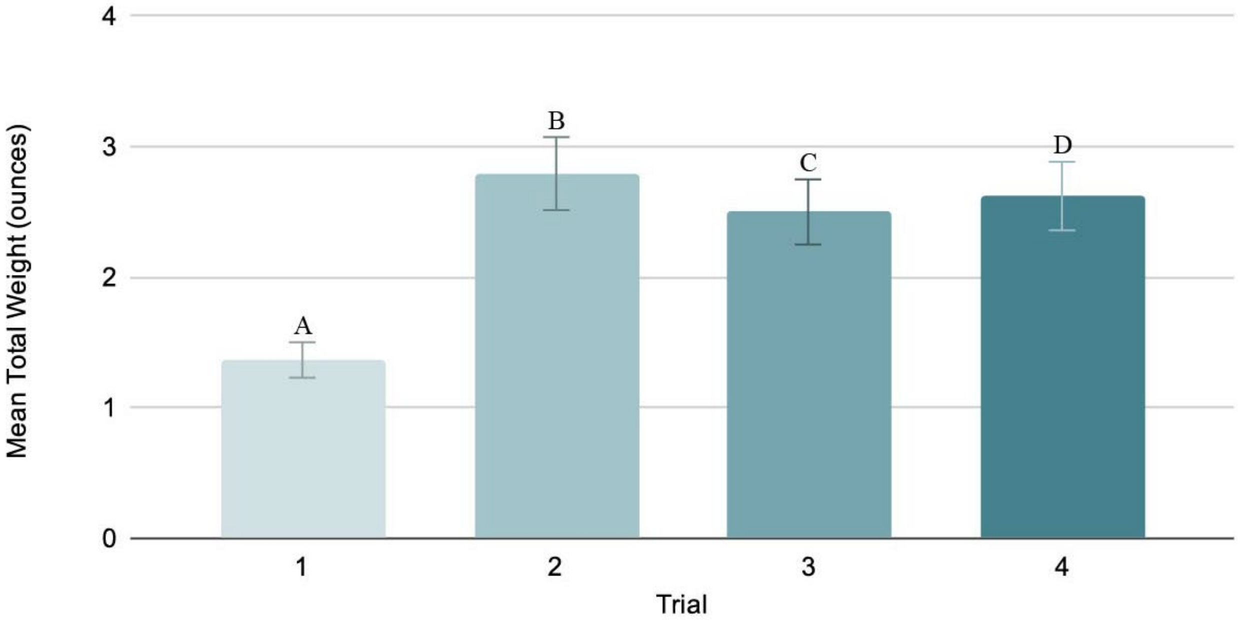


Figure 3.20: Mean total weight for ***Trial 1*** *A=1.367 ounce (P=0.0001),* ***Trial 2*** *B=2.794 ounces (P=0.0001),* ***Trial 3*** *C=2.500 ounces (P=0.1303), and* ***Trial 4*** *D=2.622 ounces (P=0.0122)*

Unlike the other variables, mat type was viewed as significant in relation to total weight. The CocoTek mat (Mat [CO]) had a p-value of 0.0124 and a t-ratio of -2.57 while the Envelor mat (Mat [EV]) had a p-value of 0.0124 and a t-ratio of 2.57. This indicated that the Envelor mat had a higher correlation regarding total weight. The significant p-value for the Envelor mat is confirmed by the mean total weight success shown in Figure 3.21. The higher mean total weight could lead to the conclusion that the Envelor mat is better for biomass production than the CocoTek mat.

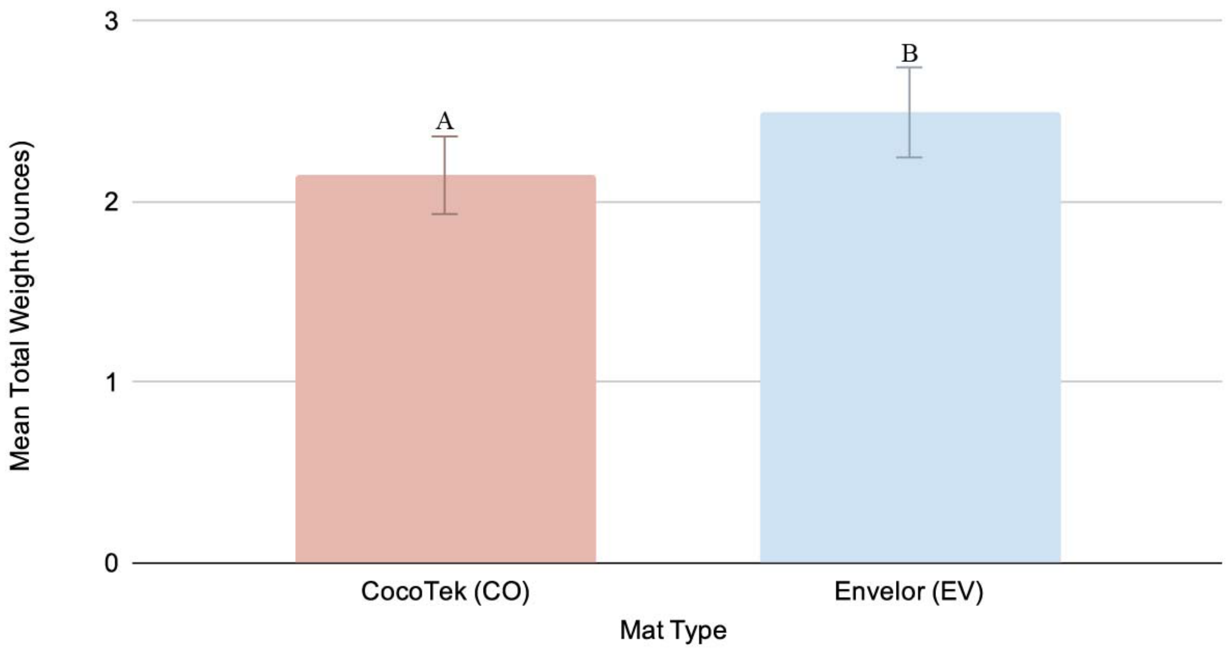
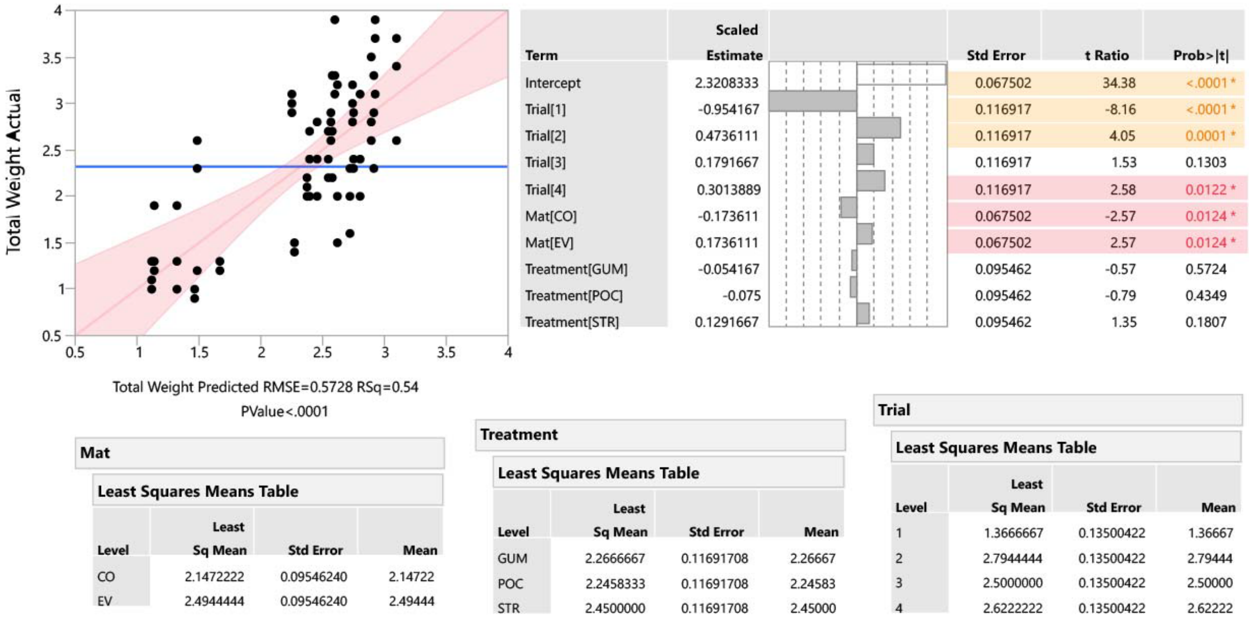


Figure 3.21: Mean total weight (ounces) for mat type ***CocoTek (CO)*** *A=2.147 ounces (P=0.0124), and* ***Envelor (EV)*** *B=2.494 ounces (P=0.0124)*



Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3208333	0.067502	34.38	<.0001 *
Trial[1]	-0.954167	0.116917	-8.16	<.0001 *
Trial[2]	0.4736111	0.116917	4.05	0.0001 *
Trial[3]	0.1791667	0.116917	1.53	0.1303
Trial[4]	0.3013889	0.116917	2.58	0.0122 *
Mat[CO]	-0.173611	0.067502	-2.57	0.0124 *
Mat[EV]	0.1736111	0.067502	2.57	0.0124 *
Treatment[GUM]	-0.054167	0.095462	-0.57	0.5724
Treatment[POC]	-0.075	0.095462	-0.79	0.4349
Treatment[STR]	0.1291667	0.095462	1.35	0.1807

Mat

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
CO	2.1472222	0.09546240	2.14722
EV	2.4944444	0.09546240	2.49444

Treatment

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
GUM	2.2666667	0.11691708	2.26667
POC	2.2458333	0.11691708	2.24583
STR	2.4500000	0.11691708	2.45000

Trial

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
1	1.3666667	0.13500422	1.36667
2	2.7944444	0.13500422	2.79444
3	2.5000000	0.13500422	2.50000
4	2.6222222	0.13500422	2.62222

Figure 3.22: Correlation response for total weight

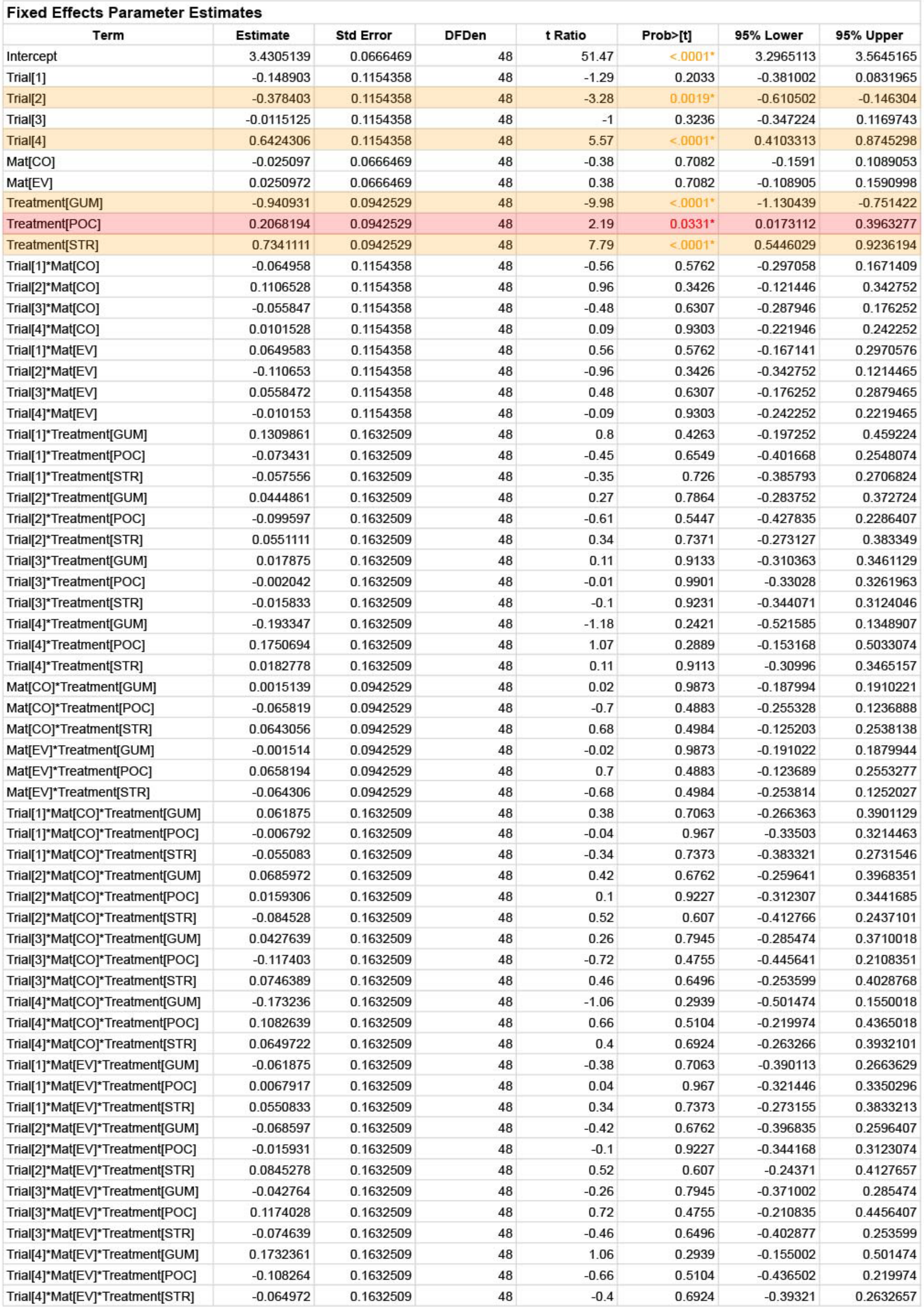
Overall trial and treatment had the most significant correlations regarding the variables of stem length, stem weight, stem count, and total weight. Trial 4 had a positive correlation regarding all the variables analyzed. This was to be expected as trial 4 had the highest germination rate out of all the trials. The correlation analysis also presented that the Konjac gum treatment had a negative correlation regarding stem length, stem weight, and stem count. This indicated that the Konjac gum treatment was the least effective treatment in the experiment. Straight seed had a positive correlation regarding stem length, stem weight, and stem count. Straight seed performing better than both the pocket and Konjac gum treatments was not expected since the need for a secondary adhesive or holding technique was anticipated for germination.

The correlation models presented which variables were impacted by the different trials, mat types, and treatments. Based on these results, fit mixed models were conducted to examine if any combinations of variables had a significant effect on the microgreen growth cycles. All the fit mixed models used trial 4, Envelor mat, and the straight seed treatment as reference since it had the highest performance in the correlation analyses.

3.4.3 Fit Mixed Models

Based on the strong correlations found for trial and treatment, fit fixed models were conducted to find possible significant combinations of variables. The fit fixed models suggested that the sequence of trial and treatment, especially trial 4 and the straight seed treatment, created a successful combination. The following section examines the results of the fit mixed model analysis in detail.

The first fit mixed model conducted was for stem length (Table 3.1). The fit mixed model data confirmed the analysis conducted in the correlation model with significant values for trial 2 (P=0.0019), trial 4 (P=0.0001), Konjac Gum treatment (P=0.0001), and straight seed treatment (P=0.0001) for stem length. In relation to stem length, there was no significant combination of variables. The most significant factors were trial and treatment, with trial 4 and treatment straight seed having the most success. Trial 2 and the gum treatment had significant negative t-ratios which concludes that in relation to stem length, these variables were the least successful.



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>|t|	95% Lower	95% Upper
Intercept	3.4305139	0.0666469	48	51.47	<.0001*	3.2965113	3.5645165
Trial[1]	-0.148903	0.1154358	48	-1.29	0.2033	-0.381002	0.0831965
Trial[2]	-0.378403	0.1154358	48	-3.28	0.0019*	-0.610502	-0.146304
Trial[3]	-0.0115125	0.1154358	48	-1	0.3236	-0.347224	0.1169743
Trial[4]	0.6424306	0.1154358	48	5.57	<.0001*	0.4103313	0.8745298
Mat[CO]	-0.025097	0.0666469	48	-0.38	0.7082	-0.1591	0.1089053
Mat[EV]	0.0250972	0.0666469	48	0.38	0.7082	-0.108905	0.1590998
Treatment[GUM]	-0.940931	0.0942529	48	-9.98	<.0001*	-1.130439	-0.751422
Treatment[POC]	0.2068194	0.0942529	48	2.19	0.0331*	0.0173112	0.3963277
Treatment[STR]	0.7341111	0.0942529	48	7.79	<.0001*	0.5446029	0.9236194
Trial[1]*Mat[CO]	-0.064958	0.1154358	48	-0.56	0.5762	-0.297058	0.1671409
Trial[2]*Mat[CO]	0.1106528	0.1154358	48	0.96	0.3426	-0.121446	0.342752
Trial[3]*Mat[CO]	-0.055847	0.1154358	48	-0.48	0.6307	-0.287946	0.176252
Trial[4]*Mat[CO]	0.0101528	0.1154358	48	0.09	0.9303	-0.221946	0.242252
Trial[1]*Mat[EV]	0.0649583	0.1154358	48	0.56	0.5762	-0.167141	0.2970576
Trial[2]*Mat[EV]	-0.110653	0.1154358	48	-0.96	0.3426	-0.342752	0.1214465
Trial[3]*Mat[EV]	0.0558472	0.1154358	48	0.48	0.6307	-0.176252	0.2879465
Trial[4]*Mat[EV]	-0.010153	0.1154358	48	-0.09	0.9303	-0.242252	0.2219465
Trial[1]*Treatment[GUM]	0.1309861	0.1632509	48	0.8	0.4263	-0.197252	0.459224
Trial[1]*Treatment[POC]	-0.073431	0.1632509	48	-0.45	0.6549	-0.401668	0.2548074
Trial[1]*Treatment[STR]	-0.057556	0.1632509	48	-0.35	0.726	-0.385793	0.2706824
Trial[2]*Treatment[GUM]	0.0444861	0.1632509	48	0.27	0.7864	-0.283752	0.372724
Trial[2]*Treatment[POC]	-0.099597	0.1632509	48	-0.61	0.5447	-0.427835	0.2286407
Trial[2]*Treatment[STR]	0.0551111	0.1632509	48	0.34	0.7371	-0.273127	0.383349
Trial[3]*Treatment[GUM]	0.017875	0.1632509	48	0.11	0.9133	-0.310363	0.3461129
Trial[3]*Treatment[POC]	-0.002042	0.1632509	48	-0.01	0.9901	-0.33028	0.3261963
Trial[3]*Treatment[STR]	-0.015833	0.1632509	48	-0.1	0.9231	-0.344071	0.3124046
Trial[4]*Treatment[GUM]	-0.193347	0.1632509	48	-1.18	0.2421	-0.521585	0.1348907
Trial[4]*Treatment[POC]	0.1750694	0.1632509	48	1.07	0.2889	-0.153168	0.5033074
Trial[4]*Treatment[STR]	0.0182778	0.1632509	48	0.11	0.9113	-0.30996	0.3465157
Mat[CO]*Treatment[GUM]	0.0015139	0.0942529	48	0.02	0.9873	-0.187994	0.1910221
Mat[CO]*Treatment[POC]	-0.065819	0.0942529	48	-0.7	0.4883	-0.255328	0.1236888
Mat[CO]*Treatment[STR]	0.0643056	0.0942529	48	0.68	0.4984	-0.125203	0.2538138
Mat[EV]*Treatment[GUM]	-0.001514	0.0942529	48	-0.02	0.9873	-0.191022	0.1879944
Mat[EV]*Treatment[POC]	0.0658194	0.0942529	48	0.7	0.4883	-0.123689	0.2553277
Mat[EV]*Treatment[STR]	-0.064306	0.0942529	48	-0.68	0.4984	-0.253814	0.1252027
Trial[1]*Mat[CO]*Treatment[GUM]	0.061875	0.1632509	48	0.38	0.7063	-0.266363	0.3901129
Trial[1]*Mat[CO]*Treatment[POC]	-0.006792	0.1632509	48	-0.04	0.967	-0.33503	0.3214463
Trial[1]*Mat[CO]*Treatment[STR]	-0.055083	0.1632509	48	-0.34	0.7373	-0.383321	0.2731546
Trial[2]*Mat[CO]*Treatment[GUM]	0.0685972	0.1632509	48	0.42	0.6762	-0.259641	0.3968351
Trial[2]*Mat[CO]*Treatment[POC]	0.0159306	0.1632509	48	0.1	0.9227	-0.312307	0.3441685
Trial[2]*Mat[CO]*Treatment[STR]	-0.084528	0.1632509	48	0.52	0.607	-0.412766	0.2437101
Trial[3]*Mat[CO]*Treatment[GUM]	0.0427639	0.1632509	48	0.26	0.7945	-0.285474	0.3710018
Trial[3]*Mat[CO]*Treatment[POC]	-0.117403	0.1632509	48	-0.72	0.4755	-0.445641	0.2108351
Trial[3]*Mat[CO]*Treatment[STR]	0.0746389	0.1632509	48	0.46	0.6496	-0.253599	0.4028768
Trial[4]*Mat[CO]*Treatment[GUM]	-0.173236	0.1632509	48	-1.06	0.2939	-0.501474	0.1550018
Trial[4]*Mat[CO]*Treatment[POC]	0.1082639	0.1632509	48	0.66	0.5104	-0.219974	0.4365018
Trial[4]*Mat[CO]*Treatment[STR]	0.0649722	0.1632509	48	0.4	0.6924	-0.263266	0.3932101
Trial[1]*Mat[EV]*Treatment[GUM]	-0.061875	0.1632509	48	-0.38	0.7063	-0.390113	0.2663629
Trial[1]*Mat[EV]*Treatment[POC]	0.0067917	0.1632509	48	0.04	0.967	-0.321446	0.3350296
Trial[1]*Mat[EV]*Treatment[STR]	0.0550833	0.1632509	48	0.34	0.7373	-0.273155	0.3833213
Trial[2]*Mat[EV]*Treatment[GUM]	-0.068597	0.1632509	48	-0.42	0.6762	-0.396835	0.2596407
Trial[2]*Mat[EV]*Treatment[POC]	-0.015931	0.1632509	48	-0.1	0.9227	-0.344168	0.3123074
Trial[2]*Mat[EV]*Treatment[STR]	0.0845278	0.1632509	48	0.52	0.607	-0.24371	0.4127657
Trial[3]*Mat[EV]*Treatment[GUM]	-0.042764	0.1632509	48	-0.26	0.7945	-0.371002	0.285474
Trial[3]*Mat[EV]*Treatment[POC]	0.1174028	0.1632509	48	0.72	0.4755	-0.210835	0.4456407
Trial[3]*Mat[EV]*Treatment[STR]	-0.074639	0.1632509	48	-0.46	0.6496	-0.402877	0.253599
Trial[4]*Mat[EV]*Treatment[GUM]	0.1732361	0.1632509	48	1.06	0.2939	-0.155002	0.501474
Trial[4]*Mat[EV]*Treatment[POC]	-0.108264	0.1632509	48	-0.66	0.5104	-0.436502	0.219974
Trial[4]*Mat[EV]*Treatment[STR]	-0.064972	0.1632509	48	-0.4	0.6924	-0.39321	0.2632657

Table 3.1: Fit mixed model for stem length

Table 3.2 examines the fit mixed model for stem weight. The fit mixed model data confirmed the analysis conducted in the correlation model and presents 11 different combinations of variables that had significant p-values and t-ratios. The combination of trial 1 and the Konjac Gum treatment (Trial [1] *Treatment [GUM]) had a p-value of 0.0001 and a t-ratio of 7.75, trial 1 and the pocket treatment (Trial [1] *Treatment [POC]) had a p-value of 0.0012 and a t-ratio of -3.43, and trial 1 and the straight seed treatment (Trial [1] *Treatment [STR]) had a p-value of 0.0001 and a t-ratio of -4.32. These values show that trial 1 stem weight was significantly impacted by treatment. The pocket treatment and straight seed treatment had negative t-ratios which reveals a lower success rate than the positive t-ratio in the gum treatment for trial 1.

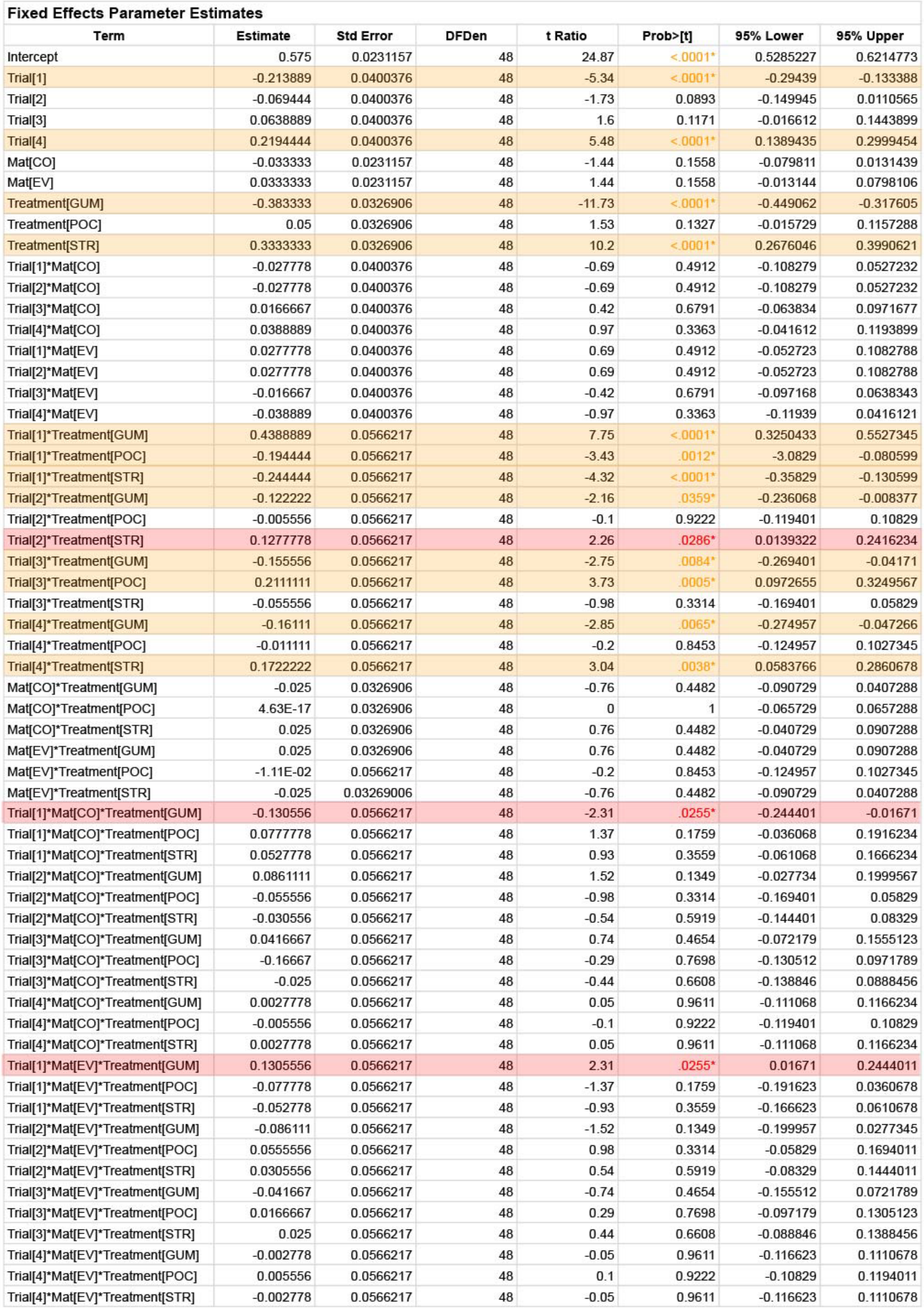
For trial 2 the combination of trial 2 and the Konjac Gum treatment (Trial [2] *Treatment [GUM]) had a p-value of 0.0359 and a t-ratio of -2.16, and trial 2 and the straight seed treatment (Trial [2] *Treatment [STR]) had a p-value of 0.0286 and a t-ratio of 2.26. These values show that for trial 2, treatment was a significant factor in relation to stem weight. The treatment straight seed had a positive t-ratio which indicates an increase in stem weight during trial 2 while the Konjac Gum treatment exhibited a negative t-ratio and consequently, a decrease in overall stem weight.

For trial 3 the variable combinations of trial 3 and the Konjac gum treatment (Trial [3] *Treatment [GUM]) had a p-value of 0.0084 and a t-ratio of -2.75, and trial 3 and the pocket treatment (Trial [3] *Treatment [POC]) had a p-value of 0.0005 and a t-ratio of 3.73. These values represent in trial 3 the pocket treatment had an increase in stem weight while the Konjac Gum treatment had a significant decrease in stem weight.

For trial 4 the variable combinations of trial 4 and Konjac Gum (Trial [4] *Treatment [GUM]) had a p-value of 0.0065 and a t-ratio of -2.85, and trial four and the straight seed treatment (Trial [4] *Treatment [STR]) had a p-value of 0.0038 and a t-ratio of 3.04. These values represent in trial 4 the Konjac Gum treatment had a lower stem weight while the straight seed treatment had an increase in stem weight.

For stem weight, the mat type alone did not present a significant difference but in the variable combination of trial 1, CocoTek mat, and the Konjac Gum treatment (Trial [1] *Mat [CO]*Treatment [GUM]) had a p-value of 0.0255 and a t-ratio of -2.31. This negative t-ratio suggests that the combination of the CocoTek mat and the Konjac Gum treatment had a negative impact on the stem weight for trial 1. On the contrary, the combination of trial 1, Envelor mat, and the Konjac Gum treatment (Trial [1] *Mat [EV]*Treatment [GUM]) had a p-value of 0.0255 and a t-ratio of 2.31. These values argue that the combination of the Envelor mat and Konjac Gum treatment had a negative impact on the stem weight in trial 1.

From the fit mixed model analysis, trial and treatment are the 2 variables with the most significant impact on stem weight. In general, the Konjac Gum treatment had a negative effect on stem weight and the straight seed treatment had a positive effect.



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>[t]	95% Lower	95% Upper
Intercept	0.575	0.0231157	48	24.87	<.0001*	0.5285227	0.6214773
Trial[1]	-0.213889	0.0400376	48	-5.34	<.0001*	-0.29439	-0.133388
Trial[2]	-0.069444	0.0400376	48	-1.73	0.0893	-0.149945	0.0110565
Trial[3]	0.0638889	0.0400376	48	1.6	0.1171	-0.016612	0.1443899
Trial[4]	0.2194444	0.0400376	48	5.48	<.0001*	0.1389435	0.2999454
Mat[CO]	-0.033333	0.0231157	48	-1.44	0.1558	-0.079811	0.0131439
Mat[EV]	0.0333333	0.0231157	48	1.44	0.1558	-0.013144	0.0798106
Treatment[GUM]	-0.383333	0.0326906	48	-11.73	<.0001*	-0.449062	-0.317605
Treatment[POC]	0.05	0.0326906	48	1.53	0.1327	-0.015729	0.1157288
Treatment[STR]	0.3333333	0.0326906	48	10.2	<.0001*	0.2676046	0.3990621
Trial[1]*Mat[CO]	-0.027778	0.0400376	48	-0.69	0.4912	-0.108279	0.0527232
Trial[2]*Mat[CO]	-0.027778	0.0400376	48	-0.69	0.4912	-0.108279	0.0527232
Trial[3]*Mat[CO]	0.0166667	0.0400376	48	0.42	0.6791	-0.063834	0.0971677
Trial[4]*Mat[CO]	0.0388889	0.0400376	48	0.97	0.3363	-0.041612	0.1193899
Trial[1]*Mat[EV]	0.0277778	0.0400376	48	0.69	0.4912	-0.052723	0.1082788
Trial[2]*Mat[EV]	0.0277778	0.0400376	48	0.69	0.4912	-0.052723	0.1082788
Trial[3]*Mat[EV]	-0.016667	0.0400376	48	-0.42	0.6791	-0.097168	0.0638343
Trial[4]*Mat[EV]	-0.038889	0.0400376	48	-0.97	0.3363	-0.11939	0.0416121
Trial[1]*Treatment[GUM]	0.4388889	0.0566217	48	7.75	<.0001*	0.3250433	0.5527345
Trial[1]*Treatment[POC]	-0.194444	0.0566217	48	-3.43	.0012*	-3.0829	-0.080599
Trial[1]*Treatment[STR]	-0.244444	0.0566217	48	-4.32	<.0001*	-0.35829	-0.130599
Trial[2]*Treatment[GUM]	-0.122222	0.0566217	48	-2.16	.0359*	-0.236068	-0.008377
Trial[2]*Treatment[POC]	-0.005556	0.0566217	48	-0.1	0.9222	-0.119401	0.10829
Trial[2]*Treatment[STR]	0.1277778	0.0566217	48	2.26	.0286*	0.0139322	0.2416234
Trial[3]*Treatment[GUM]	-0.155556	0.0566217	48	-2.75	.0084*	-0.269401	-0.04171
Trial[3]*Treatment[POC]	0.2111111	0.0566217	48	3.73	.0005*	0.0972655	0.3249567
Trial[3]*Treatment[STR]	-0.055556	0.0566217	48	-0.98	0.3314	-0.169401	0.05829
Trial[4]*Treatment[GUM]	-0.16111	0.0566217	48	-2.85	.0065*	-0.274957	-0.047266
Trial[4]*Treatment[POC]	-0.011111	0.0566217	48	-0.2	0.8453	-0.124957	0.1027345
Trial[4]*Treatment[STR]	0.1722222	0.0566217	48	3.04	.0038*	0.0583766	0.2860678
Mat[CO]*Treatment[GUM]	-0.025	0.0326906	48	-0.76	0.4482	-0.090729	0.0407288
Mat[CO]*Treatment[POC]	4.63E-17	0.0326906	48	0	1	-0.065729	0.0657288
Mat[CO]*Treatment[STR]	0.025	0.0326906	48	0.76	0.4482	-0.040729	0.0907288
Mat[EV]*Treatment[GUM]	0.025	0.0326906	48	0.76	0.4482	-0.040729	0.0907288
Mat[EV]*Treatment[POC]	-1.11E-02	0.0566217	48	-0.2	0.8453	-0.124957	0.1027345
Mat[EV]*Treatment[STR]	-0.025	0.03269006	48	-0.76	0.4482	-0.090729	0.0407288
Trial[1]*Mat[CO]*Treatment[GUM]	-0.130556	0.0566217	48	-2.31	.0255*	-0.244401	-0.01671
Trial[1]*Mat[CO]*Treatment[POC]	0.0777778	0.0566217	48	1.37	0.1759	-0.036068	0.1916234
Trial[1]*Mat[CO]*Treatment[STR]	0.0527778	0.0566217	48	0.93	0.3559	-0.061068	0.1666234
Trial[2]*Mat[CO]*Treatment[GUM]	0.0861111	0.0566217	48	1.52	0.1349	-0.027734	0.1999567
Trial[2]*Mat[CO]*Treatment[POC]	-0.055556	0.0566217	48	-0.98	0.3314	-0.169401	0.05829
Trial[2]*Mat[CO]*Treatment[STR]	-0.030556	0.0566217	48	-0.54	0.5919	-0.144401	0.08329
Trial[3]*Mat[CO]*Treatment[GUM]	0.0416667	0.0566217	48	0.74	0.4654	-0.072179	0.1555123
Trial[3]*Mat[CO]*Treatment[POC]	-0.16667	0.0566217	48	-0.29	0.7698	-0.130512	0.0971789
Trial[3]*Mat[CO]*Treatment[STR]	-0.025	0.0566217	48	-0.44	0.6608	-0.138846	0.0888456
Trial[4]*Mat[CO]*Treatment[GUM]	0.0027778	0.0566217	48	0.05	0.9611	-0.111068	0.1166234
Trial[4]*Mat[CO]*Treatment[POC]	-0.005556	0.0566217	48	-0.1	0.9222	-0.119401	0.10829
Trial[4]*Mat[CO]*Treatment[STR]	0.0027778	0.0566217	48	0.05	0.9611	-0.111068	0.1166234
Trial[1]*Mat[EV]*Treatment[GUM]	0.1305556	0.0566217	48	2.31	.0255*	0.01671	0.2444011
Trial[1]*Mat[EV]*Treatment[POC]	-0.077778	0.0566217	48	-1.37	0.1759	-0.191623	0.0360678
Trial[1]*Mat[EV]*Treatment[STR]	-0.052778	0.0566217	48	-0.93	0.3559	-0.166623	0.0610678
Trial[2]*Mat[EV]*Treatment[GUM]	-0.086111	0.0566217	48	-1.52	0.1349	-0.199957	0.0277345
Trial[2]*Mat[EV]*Treatment[POC]	0.0555556	0.0566217	48	0.98	0.3314	-0.05829	0.1694011
Trial[2]*Mat[EV]*Treatment[STR]	0.0305556	0.0566217	48	0.54	0.5919	-0.08329	0.1444011
Trial[3]*Mat[EV]*Treatment[GUM]	-0.041667	0.0566217	48	-0.74	0.4654	-0.155512	0.0721789
Trial[3]*Mat[EV]*Treatment[POC]	0.0166667	0.0566217	48	0.29	0.7698	-0.097179	0.1305123
Trial[3]*Mat[EV]*Treatment[STR]	0.025	0.0566217	48	0.44	0.6608	-0.088846	0.1388456
Trial[4]*Mat[EV]*Treatment[GUM]	-0.002778	0.0566217	48	-0.05	0.9611	-0.116623	0.1110678
Trial[4]*Mat[EV]*Treatment[POC]	0.005556	0.0566217	48	0.1	0.9222	-0.10829	0.1194011
Trial[4]*Mat[EV]*Treatment[STR]	-0.002778	0.0566217	48	-0.05	0.9611	-0.116623	0.1110678

Table 3.2: Fit mixed model for stem weight

Table 3.3 details the fit fixed model analysis for stem count. The fit mixed model data confirmed the analysis conducted in the correlation model and presents 13 combinations of variables that were found to be significant for stem count. The combination of trial 1 and the Konjac Gum treatment (Trial [1] *Treatment [GUM]) had a p-value of 0.0001 and a t-ratio of 6.14, trial 1 and the pocket treatment (Trial [1] *Treatment [POC]) had a p-value of 0.0024 and a t-ratio of -3.2, trial 1 and the straight seed treatment (Trial [1] *Treatment [STR]) had a p-value of 0.0051 and a t-ratio of -2.94. These values show that trial one stem count was significantly impacted by treatment. The pocket treatment and straight seed treatment had negative t-ratios which reveals a lower success rate than the positive t-ratio in the gum treatment for trial 1.

For trial 2, the combination of trial 2 and the Konjac gum treatment (Trial [2] *Treatment [GUM]) had a p-value of 0.0497 and a t-ratio of 2.01. This positive value for the Konjac Gum Treatment in trial 2 could be attributed to the increase in stem count from trial 1 to trial 2. Although the stem count for trial 2 was still the lowest out of the three treatments in trial 2, there was a significant increase from trial 1.

For trial 3, the combination of trial 3 and the Konjac Gum treatment (Trial [3] *Treatment [GUM]) had a p-value of 0.0026 and a t-ratio of -3.17, trial 3 and the pocket treatment (Trial [3] *Treatment [POC]) had a p-value of 0.0313 and a t-ratio of 2.22. The negative t-ratio for the Konjac Gum treatment indicates that there was a negative impact on the stem count in trial 3 while the pocket treatment had a positive t-ratio and a resulting positive impact on the stem count.

For trial 4, the combination of trial 4 and the Konjac Gum treatment (Trial [4] *Treatment [GUM]) had a p-value of 0.0001 and a t-ratio of -4.98, trial four and the pocket treatment (Trial

[4] *Treatment [POC]) had a p-value of 0.0083 and a t-ratio of 2.75, trial 4 and the straight seed treatment (Trial [4] *Treatment [STR]) had a p-value of 0.0306 and a t-ratio of 2.23. For trial 4, treatment was a significant factor in relation to stem count. The Konjac Gum treatment had a negative t-ratio which indicates a negative effect on stem count while the pocket treatment and straight seed treatment both had positive t-ratios, resulting in an increase in stem count for trial 4. Figure 3.23 shows images of the straight seed treatment, pocket treatment, and the Konjac Gum treatment for Envelor sample 3 on the last day of the germination cycle from trial 4 to show the difference in microgreen coverage while figure 3.24 shows the same for CocoTek.

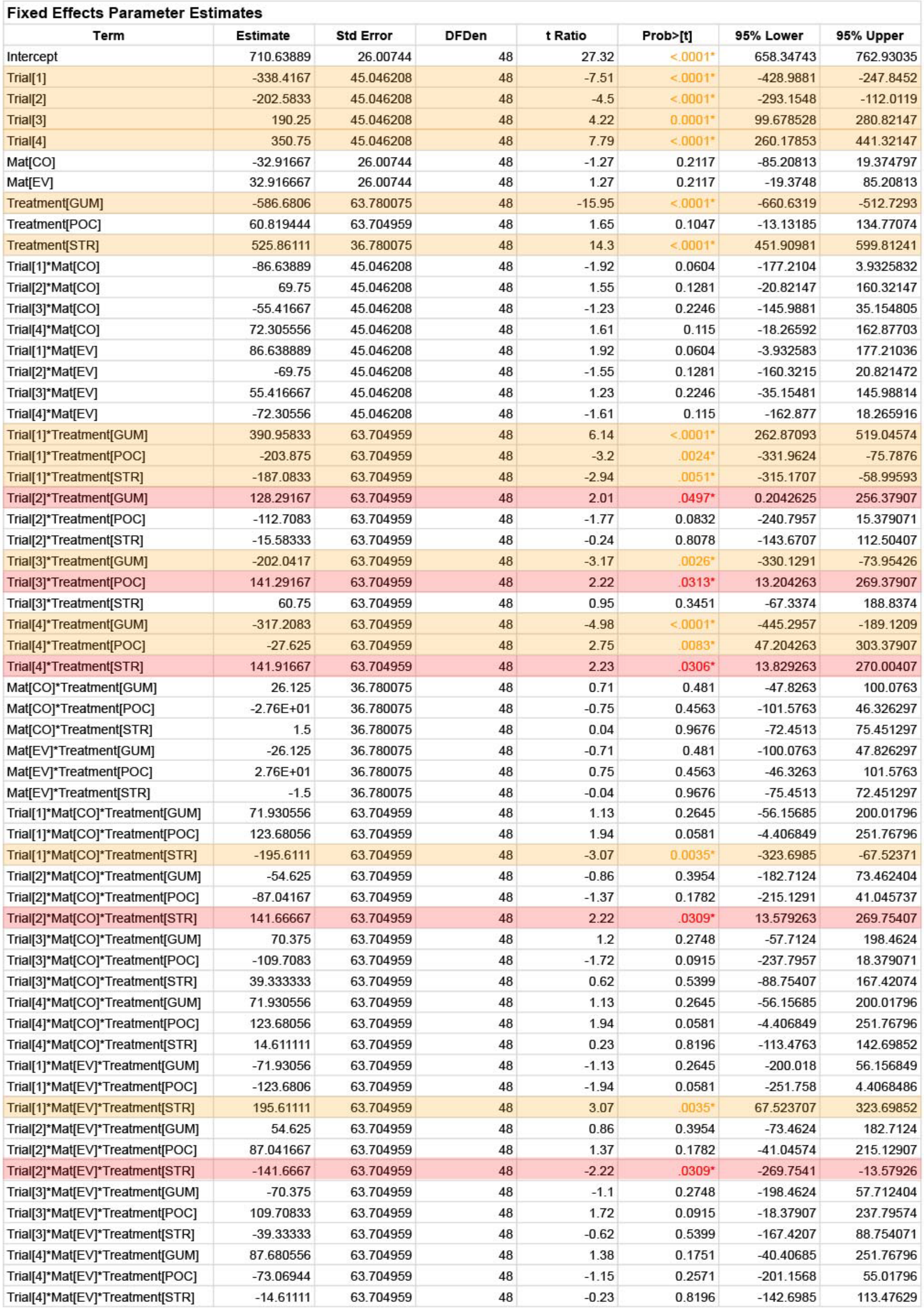
Figure 3.23: Envelor mat straight seed sample 3 (left), pocket sample 3 (center), and Konjac Gum sample 3 treatments from the last day of trial 4

Figure 3.24: CocoTek mat straight seed sample 3 (left), pocket sample 3 (center), and Konjac Gum sample 3 treatments from the last day of trial 4

Like stem length and stem weight, mat type alone did not influence the overall stem count. However, the combination of trial 1, CocoTek mat, and the straight seed treatment (Trial [1] *Mat [CO]*Treatment [STR]) had a p-value of 0.0035 and a t-ratio of -3.07. This negative t-ratio indicates that the combination of the CocoTek mat and the straight seed treatment in trial 1 had a negative impact on stem count. The increase in the t-ratio for trial 2 indicates a higher stem count success than was found in trial 1.

The Envelor mat was also found to have a significant value when in combination with trial and treatment. The combination of trial 1, Envelor mat, and the straight seed treatment had a p-value of 0.0035 and a t-ratio of 3.07, and trial 2, Envelor mat, and straight seed treatment (Trial [2] *Mat [EV]*Treatment [STR]) had a p-value of 0.0309 and a t-ratio of -2.22. These values present that the combination of Envelor mat and straight seed treatment in trial 1 had a positive impact on stem count.

From the fit mixed model analysis, trial and treatment are the two variables with the most significant impact on stem count. In general, the Konjac Gum treatment had a negative effect on stem count and the straight seed treatment had a positive effect.



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>[t]	95% Lower	95% Upper
Intercept	710.63889	26.00744	48	27.32	<.0001*	658.34743	762.93035
Trial[1]	-338.4167	45.046208	48	-7.51	<.0001*	-428.9881	-247.8452
Trial[2]	-202.5833	45.046208	48	-4.5	<.0001*	-293.1548	-112.0119
Trial[3]	190.25	45.046208	48	4.22	0.0001*	99.678528	280.82147
Trial[4]	350.75	45.046208	48	7.79	<.0001*	260.17853	441.32147
Mat[CO]	-32.91667	26.00744	48	-1.27	0.2117	-85.20813	19.374797
Mat[EV]	32.916667	26.00744	48	1.27	0.2117	-19.3748	85.20813
Treatment[GUM]	-586.6806	63.780075	48	-15.95	<.0001*	-660.6319	-512.7293
Treatment[POC]	60.819444	63.704959	48	1.65	0.1047	-13.13185	134.77074
Treatment[STR]	525.86111	36.780075	48	14.3	<.0001*	451.90981	599.81241
Trial[1]*Mat[CO]	-86.63889	45.046208	48	-1.92	0.0604	-177.2104	3.9325832
Trial[2]*Mat[CO]	69.75	45.046208	48	1.55	0.1281	-20.82147	160.32147
Trial[3]*Mat[CO]	-55.41667	45.046208	48	-1.23	0.2246	-145.9881	35.154805
Trial[4]*Mat[CO]	72.305556	45.046208	48	1.61	0.115	-18.26592	162.87703
Trial[1]*Mat[EV]	86.638889	45.046208	48	1.92	0.0604	-3.932583	177.21036
Trial[2]*Mat[EV]	-69.75	45.046208	48	-1.55	0.1281	-160.3215	20.821472
Trial[3]*Mat[EV]	55.416667	45.046208	48	1.23	0.2246	-35.15481	145.98814
Trial[4]*Mat[EV]	-72.30556	45.046208	48	-1.61	0.115	-162.877	18.265916
Trial[1]*Treatment[GUM]	390.95833	63.704959	48	6.14	<.0001*	262.87093	519.04574
Trial[1]*Treatment[POC]	-203.875	63.704959	48	-3.2	.0024*	-331.9624	-75.7876
Trial[1]*Treatment[STR]	-187.0833	63.704959	48	-2.94	.0051*	-315.1707	-58.99593
Trial[2]*Treatment[GUM]	128.29167	63.704959	48	2.01	.0497*	0.2042625	256.37907
Trial[2]*Treatment[POC]	-112.7083	63.704959	48	-1.77	0.0832	-240.7957	15.379071
Trial[2]*Treatment[STR]	-15.58333	63.704959	48	-0.24	0.8078	-143.6707	112.50407
Trial[3]*Treatment[GUM]	-202.0417	63.704959	48	-3.17	.0026*	-330.1291	-73.95426
Trial[3]*Treatment[POC]	141.29167	63.704959	48	2.22	.0313*	13.204263	269.37907
Trial[3]*Treatment[STR]	60.75	63.704959	48	0.95	0.3451	-67.3374	188.8374
Trial[4]*Treatment[GUM]	-317.2083	63.704959	48	-4.98	<.0001*	-445.2957	-189.1209
Trial[4]*Treatment[POC]	-27.625	63.704959	48	2.75	.0083*	47.204263	303.37907
Trial[4]*Treatment[STR]	141.91667	63.704959	48	2.23	.0306*	13.829263	270.00407
Mat[CO]*Treatment[GUM]	26.125	36.780075	48	0.71	0.481	-47.8263	100.0763
Mat[CO]*Treatment[POC]	-2.76E+01	36.780075	48	-0.75	0.4563	-101.5763	46.326297
Mat[CO]*Treatment[STR]	1.5	36.780075	48	0.04	0.9676	-72.4513	75.451297
Mat[EV]*Treatment[GUM]	-26.125	36.780075	48	-0.71	0.481	-100.0763	47.826297
Mat[EV]*Treatment[POC]	2.76E+01	36.780075	48	0.75	0.4563	-46.3263	101.5763
Mat[EV]*Treatment[STR]	-1.5	36.780075	48	-0.04	0.9676	-75.4513	72.451297
Trial[1]*Mat[CO]*Treatment[GUM]	71.930556	63.704959	48	1.13	0.2645	-56.15685	200.01796
Trial[1]*Mat[CO]*Treatment[POC]	123.68056	63.704959	48	1.94	0.0581	-4.406849	251.76796
Trial[1]*Mat[CO]*Treatment[STR]	-195.6111	63.704959	48	-3.07	0.0035*	-323.6985	-67.52371
Trial[2]*Mat[CO]*Treatment[GUM]	-54.625	63.704959	48	-0.86	0.3954	-182.7124	73.462404
Trial[2]*Mat[CO]*Treatment[POC]	-87.04167	63.704959	48	-1.37	0.1782	-215.1291	41.045737
Trial[2]*Mat[CO]*Treatment[STR]	141.66667	63.704959	48	2.22	.0309*	13.579263	269.75407
Trial[3]*Mat[CO]*Treatment[GUM]	70.375	63.704959	48	1.2	0.2748	-57.7124	198.4624
Trial[3]*Mat[CO]*Treatment[POC]	-109.7083	63.704959	48	-1.72	0.0915	-237.7957	18.379071
Trial[3]*Mat[CO]*Treatment[STR]	39.333333	63.704959	48	0.62	0.5399	-88.75407	167.42074
Trial[4]*Mat[CO]*Treatment[GUM]	71.930556	63.704959	48	1.13	0.2645	-56.15685	200.01796
Trial[4]*Mat[CO]*Treatment[POC]	123.68056	63.704959	48	1.94	0.0581	-4.406849	251.76796
Trial[4]*Mat[CO]*Treatment[STR]	14.611111	63.704959	48	0.23	0.8196	-113.4763	142.69852
Trial[1]*Mat[EV]*Treatment[GUM]	-71.93056	63.704959	48	-1.13	0.2645	-200.018	56.156849
Trial[1]*Mat[EV]*Treatment[POC]	-123.6806	63.704959	48	-1.94	0.0581	-251.758	4.4068486
Trial[1]*Mat[EV]*Treatment[STR]	195.61111	63.704959	48	3.07	.0035*	67.523707	323.69852
Trial[2]*Mat[EV]*Treatment[GUM]	54.625	63.704959	48	0.86	0.3954	-73.4624	182.7124
Trial[2]*Mat[EV]*Treatment[POC]	87.041667	63.704959	48	1.37	0.1782	-41.04574	215.12907
Trial[2]*Mat[EV]*Treatment[STR]	-141.6667	63.704959	48	-2.22	.0309*	-269.7541	-13.57926
Trial[3]*Mat[EV]*Treatment[GUM]	-70.375	63.704959	48	-1.1	0.2748	-198.4624	57.712404
Trial[3]*Mat[EV]*Treatment[POC]	109.70833	63.704959	48	1.72	0.0915	-18.37907	237.79574
Trial[3]*Mat[EV]*Treatment[STR]	-39.33333	63.704959	48	-0.62	0.5399	-167.4207	88.754071
Trial[4]*Mat[EV]*Treatment[GUM]	87.680556	63.704959	48	1.38	0.1751	-40.40685	251.76796
Trial[4]*Mat[EV]*Treatment[POC]	-73.06944	63.704959	48	-1.15	0.2571	-201.1568	55.01796
Trial[4]*Mat[EV]*Treatment[STR]	-14.61111	63.704959	48	-0.23	0.8196	-142.6985	113.47629

Table 3.3: Fit mixed model for stem count

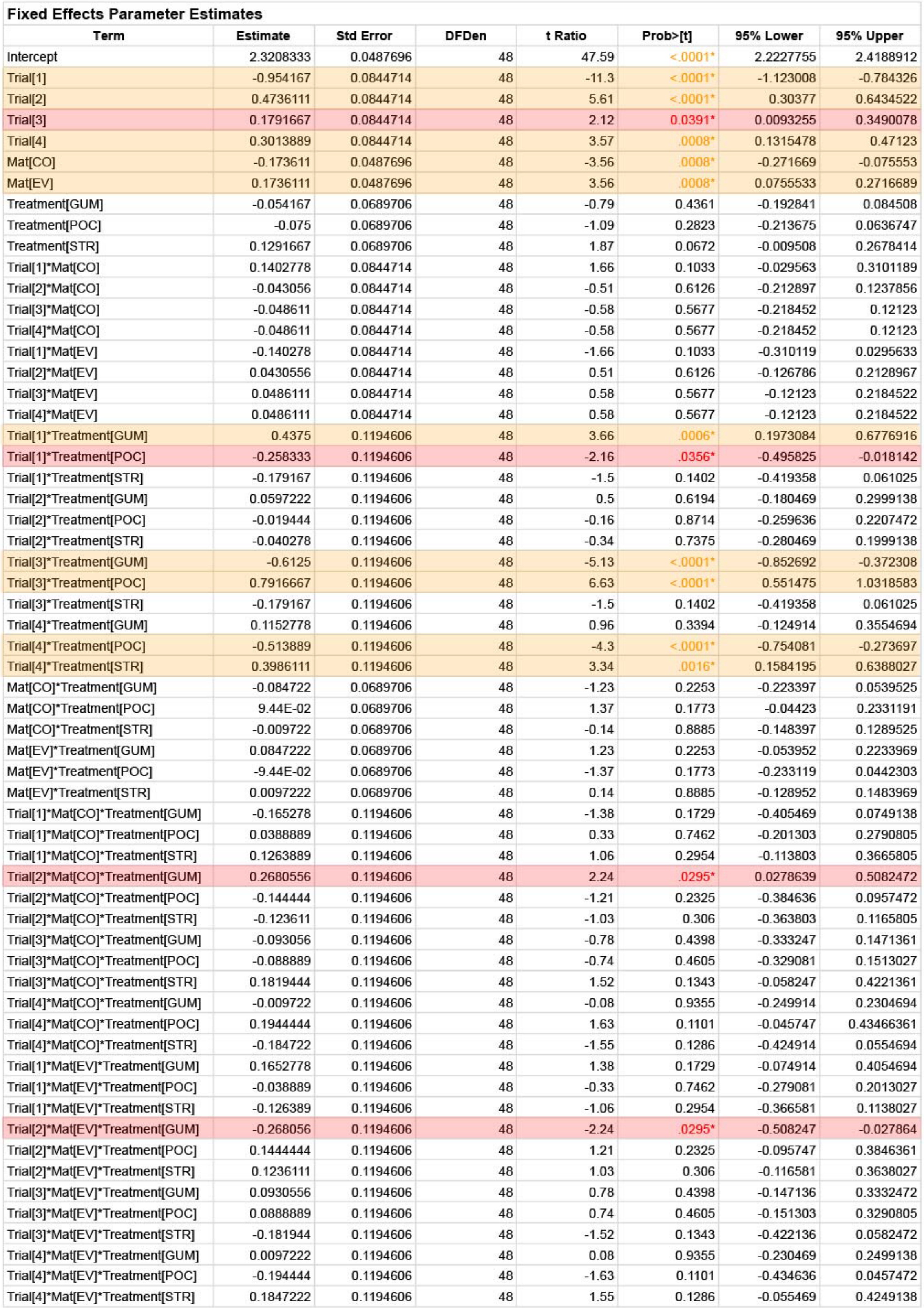
Table 3.4 details the fit fixed model analysis for total weight. Unlike the other three variables, mat type alone did have a significant effect while treatment alone did not. The fit mixed model data confirmed the analysis conducted in the correlation and found 8 combinations of variables to be significant in the fit mixed model for total weight. The combination of trial one and the Konjac Gum treatment (Trial [1] *Treatment [GUM]) had a p-value of 0.0006 and a t-ratio of 3.66, and trial one and the pocket treatment (Trial [1] *Treatment [POC]) had a p-value of 0.0356 and a t-ratio of -2.16. These values indicate that for trial 1, treatment had a significant effect on total weight; with the Konjac Gum treatment having an increased effect and the pocket treatment having a negative effect.

For trial 3, the combination of trial 3 and the Konjac Gum treatment (Trial [3] *Treatment [GUM]) had a p-value of 0.0001 and a t-ratio of -5.13, and trial 3 and the pocket treatment (Trial [3] *Treatment [POC]) had a p-value of 0.0001 and a t-ratio of 6.63. These values indicate that the Konjac Gum treatment in trial 3 had a negative impact on total weight while the pocket treatment had a positive impact based on the t-ratios.

For trial 4, the combination of trial 4 and the pocket treatment (Trial [4] *Treatment [POC]) had a p-value of 0.0001 and a t-ratio of -4.3, and trial 4 and the straight seed treatment (Trial [4] *Treatment [STR]) had a p-value of 0.0016 and a t-ratio of 3.34. These values for trial 4 indicate that the pocket treatment had a negative impact on total weight while the straight seed treatment had a positive impact.

Two combinations of trial, mat type, and treatment had a significant effect on the total weight. The first combination was trial 2, CocoTek mat, and the Konjac Gum Treatment (Trial [2] *Mat [CO]*Treatment [GUM]) with a p-value of 0.0295 and a t-ratio of 2.24. This value concludes that the Konjac Gum treatment on the CocoTek mat in trial 2 had a positive impact on the total weight. The second combination was trial 2, Envelor mat, and the Konjac Gum treatment (Trial [2] *Mat [EV]*Treatment [GUM]) with a p-value of 0.295 and a t-ratio of -2.24. This value concludes that the Konjac Gum treatment on the Envelor mat in trial 2 had a negative impact on the total weight.

From the fit mixed model analysis, trial and mat had the most significant impact on total weight while treatment was most significant in combination with trial and mat type. In relation to total weight, the Envelor had an increased effect on total weight, with the Konjac Gum and pocket treatment having the most significant effects regarding treatment.



Fixed Effects Parameter Estimates

Term	Estimate	Std Error	DFDen	t Ratio	Prob>[t]	95% Lower	95% Upper
Intercept	2.3208333	0.0487696	48	47.59	<.0001*	2.2227755	2.4188912
Trial[1]	-0.954167	0.0844714	48	-11.3	<.0001*	-1.123008	-0.784326
Trial[2]	0.4736111	0.0844714	48	5.61	<.0001*	0.30377	0.6434522
Trial[3]	0.1791667	0.0844714	48	2.12	0.0391*	0.0093255	0.3490078
Trial[4]	0.3013889	0.0844714	48	3.57	.0008*	0.1315478	0.47123
Mat[CO]	-0.173611	0.0487696	48	-3.56	.0008*	-0.271669	-0.075553
Mat[EV]	0.1736111	0.0487696	48	3.56	.0008*	0.0755533	0.2716689
Treatment[GUM]	-0.054167	0.0689706	48	-0.79	0.4361	-0.192841	0.084508
Treatment[POC]	-0.075	0.0689706	48	-1.09	0.2823	-0.213675	0.0636747
Treatment[STR]	0.1291667	0.0689706	48	1.87	0.0672	-0.009508	0.2678414
Trial[1]*Mat[CO]	0.1402778	0.0844714	48	1.66	0.1033	-0.029563	0.3101189
Trial[2]*Mat[CO]	-0.043056	0.0844714	48	-0.51	0.6126	-0.212897	0.1237856
Trial[3]*Mat[CO]	-0.048611	0.0844714	48	-0.58	0.5677	-0.218452	0.12123
Trial[4]*Mat[CO]	-0.048611	0.0844714	48	-0.58	0.5677	-0.218452	0.12123
Trial[1]*Mat[EV]	-0.140278	0.0844714	48	-1.66	0.1033	-0.310119	0.0295633
Trial[2]*Mat[EV]	0.0430556	0.0844714	48	0.51	0.6126	-0.126786	0.2128967
Trial[3]*Mat[EV]	0.0486111	0.0844714	48	0.58	0.5677	-0.12123	0.2184522
Trial[4]*Mat[EV]	0.0486111	0.0844714	48	0.58	0.5677	-0.12123	0.2184522
Trial[1]*Treatment[GUM]	0.4375	0.1194606	48	3.66	.0006*	0.1973084	0.6776916
Trial[1]*Treatment[POC]	-0.258333	0.1194606	48	-2.16	.0356*	-0.495825	-0.018142
Trial[1]*Treatment[STR]	-0.179167	0.1194606	48	-1.5	0.1402	-0.419358	0.061025
Trial[2]*Treatment[GUM]	0.0597222	0.1194606	48	0.5	0.6194	-0.180469	0.2999138
Trial[2]*Treatment[POC]	-0.019444	0.1194606	48	-0.16	0.8714	-0.259636	0.2207472
Trial[2]*Treatment[STR]	-0.040278	0.1194606	48	-0.34	0.7375	-0.280469	0.1999138
Trial[3]*Treatment[GUM]	-0.6125	0.1194606	48	-5.13	<.0001*	-0.852692	-0.372308
Trial[3]*Treatment[POC]	0.7916667	0.1194606	48	6.63	<.0001*	0.551475	1.0318583
Trial[3]*Treatment[STR]	-0.179167	0.1194606	48	-1.5	0.1402	-0.419358	0.061025
Trial[4]*Treatment[GUM]	0.1152778	0.1194606	48	0.96	0.3394	-0.124914	0.3554694
Trial[4]*Treatment[POC]	-0.513889	0.1194606	48	-4.3	<.0001*	-0.754081	-0.273697
Trial[4]*Treatment[STR]	0.3986111	0.1194606	48	3.34	.0016*	0.1584195	0.6388027
Mat[CO]*Treatment[GUM]	-0.084722	0.0689706	48	-1.23	0.2253	-0.223397	0.0539525
Mat[CO]*Treatment[POC]	9.44E-02	0.0689706	48	1.37	0.1773	-0.04423	0.2331191
Mat[CO]*Treatment[STR]	-0.009722	0.0689706	48	-0.14	0.8885	-0.148397	0.1289525
Mat[EV]*Treatment[GUM]	0.0847222	0.0689706	48	1.23	0.2253	-0.053952	0.2233969
Mat[EV]*Treatment[POC]	-9.44E-02	0.0689706	48	-1.37	0.1773	-0.233119	0.0442303
Mat[EV]*Treatment[STR]	0.0097222	0.0689706	48	0.14	0.8885	-0.128952	0.1483969
Trial[1]*Mat[CO]*Treatment[GUM]	-0.165278	0.1194606	48	-1.38	0.1729	-0.405469	0.0749138
Trial[1]*Mat[CO]*Treatment[POC]	0.0388889	0.1194606	48	0.33	0.7462	-0.201303	0.2790805
Trial[1]*Mat[CO]*Treatment[STR]	0.1263889	0.1194606	48	1.06	0.2954	-0.113803	0.3665805
Trial[2]*Mat[CO]*Treatment[GUM]	0.2680556	0.1194606	48	2.24	.0295*	0.0278639	0.5082472
Trial[2]*Mat[CO]*Treatment[POC]	-0.144444	0.1194606	48	-1.21	0.2325	-0.384636	0.0957472
Trial[2]*Mat[CO]*Treatment[STR]	-0.123611	0.1194606	48	-1.03	0.306	-0.363803	0.1165805
Trial[3]*Mat[CO]*Treatment[GUM]	-0.093056	0.1194606	48	-0.78	0.4398	-0.333247	0.1471361
Trial[3]*Mat[CO]*Treatment[POC]	-0.088889	0.1194606	48	-0.74	0.4605	-0.329081	0.1513027
Trial[3]*Mat[CO]*Treatment[STR]	0.1819444	0.1194606	48	1.52	0.1343	-0.058247	0.4221361
Trial[4]*Mat[CO]*Treatment[GUM]	-0.009722	0.1194606	48	-0.08	0.9355	-0.249914	0.2304694
Trial[4]*Mat[CO]*Treatment[POC]	0.1944444	0.1194606	48	1.63	0.1101	-0.045747	0.43466361
Trial[4]*Mat[CO]*Treatment[STR]	-0.184722	0.1194606	48	-1.55	0.1286	-0.424914	0.0554694
Trial[1]*Mat[EV]*Treatment[GUM]	0.1652778	0.1194606	48	1.38	0.1729	-0.074914	0.4054694
Trial[1]*Mat[EV]*Treatment[POC]	-0.038889	0.1194606	48	-0.33	0.7462	-0.279081	0.2013027
Trial[1]*Mat[EV]*Treatment[STR]	-0.126389	0.1194606	48	-1.06	0.2954	-0.366581	0.1138027
Trial[2]*Mat[EV]*Treatment[GUM]	-0.268056	0.1194606	48	-2.24	.0295*	-0.508247	-0.027864
Trial[2]*Mat[EV]*Treatment[POC]	0.1444444	0.1194606	48	1.21	0.2325	-0.095747	0.3846361
Trial[2]*Mat[EV]*Treatment[STR]	0.1236111	0.1194606	48	1.03	0.306	-0.116581	0.3638027
Trial[3]*Mat[EV]*Treatment[GUM]	0.0930556	0.1194606	48	0.78	0.4398	-0.147136	0.3332472
Trial[3]*Mat[EV]*Treatment[POC]	0.0888889	0.1194606	48	0.74	0.4605	-0.151303	0.3290805
Trial[3]*Mat[EV]*Treatment[STR]	-0.181944	0.1194606	48	-1.52	0.1343	-0.422136	0.0582472
Trial[4]*Mat[EV]*Treatment[GUM]	0.0097222	0.1194606	48	0.08	0.9355	-0.230469	0.2499138
Trial[4]*Mat[EV]*Treatment[POC]	-0.194444	0.1194606	48	-1.63	0.1101	-0.434636	0.0457472
Trial[4]*Mat[EV]*Treatment[STR]	0.1847222	0.1194606	48	1.55	0.1286	-0.055469	0.4249138

Table 3.4: Fit mixed model for total weight

3.5 Results

The results section reflects on the data analysis presented in the correlation and fit mixed models regarding mat type, surface manipulation, and trial. Charts are also presented and discussed to provide further explanation of the resulting data.

3.5.1 Mats

Based on the statistical analysis, mat type is a good indicator for total weight success. The Envelor mat had a p-value of 0.0124 in relation to total weight which could lead to the conclusion that it is better for biomass creation than the CocoTek mat. The Envelor mat had a range of total weights between 0.9-3.9 ounces with an average of 2.494 ounces while the CocoTek mat had a range of total weights between 1.0-3.3 ounces with an average of 2.147 ounces. The chart in Figure 3.25 represents the difference in the combined variables between the two commercial coconut coir mats of CocoTek and Envelor. The chart expresses that the Envelor mat resulted in a higher total weight, stem count, and stem length, and stem count than the CocoTek mat. Based on the correlation and fit mixed models, the increase in values for Envelor over CocoTek were found to be an insignificant factor. Other than the significance found for the Envelor mat in relation to total weight, there is no statistically significant difference between the CocoTek and Envelor mat on the growth and output of curly cress microgreens.

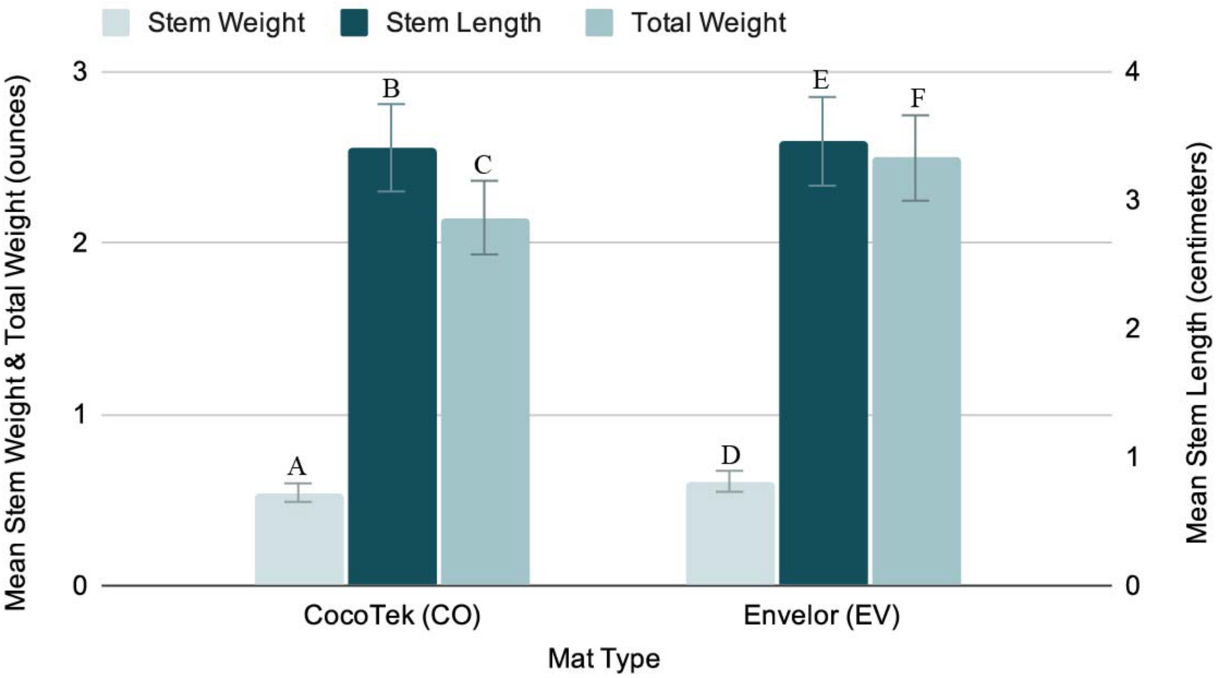


*Figure 3.25: Mat types **CocoTek (CO)** showing stem weight A=0.542 ounces (P= 0.0001), stem length B=3.405 cm (P= 0.0001), total weight C=2.147 ounces (P= 0.0001), and stem count 677.7 stems (P= 0.0001) and **Envelor (EV)** stem weight D=0.608 ounces (P=0.0001), stem length E=3.456 cm (P=0.0001), total weight F=2.494 ounces (P=0.0001), and stem count 743.6 stems (P=0.0001)*

3.5.2 Surface Manipulations

Based on the statistical analysis, treatment is a good indicator for stem length success. The straight seed treatment had the best p-value and t-ratio which deemed it the most successful treatment for increased stem length. The straight seed treatment had a stem length range between 0.8-9.5 centimeters (0.31–3.74 inches) with an average of 4.165 centimeters (1.64 inches) while Konjac Gum, the least successful treatment, had a range between 1.0-6.4 centimeters (0.40-2.52

inches) with an average of 2.489 centimeters (0.98 inches). The chart in Figure 3.26 represents the difference in the combined variables in relation to the 3 different treatments of Konjac Gum (GUM), pocket (POC), and straight seed (STR). The chart presents that the straight seed treatment was the most successful across the recorded variables. Straight seed appeared as a significant variable in the stem weight, stem count, and stem length correlations with high t-ratios in each. These analyses promote the conclusion that the straight seed treatment was the most successful for the growth and output of curly cress microgreen seeds.

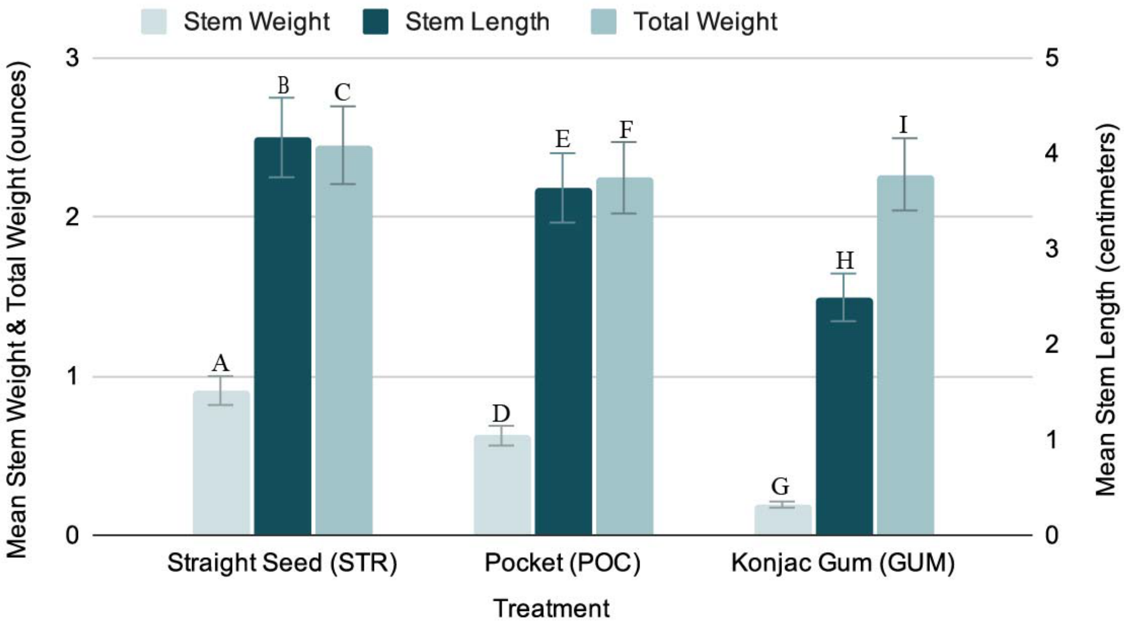


Figure 3.26: Treatments ***straight seed (STR)*** *showing stem weight A=0.908 ounce (P= 0.0001), stem length B=4.165 cm (P= 0.0001), total weight C=2.45 ounces (P= 0.0001), and stem count 1236.6 stems (P= 0.0001),* ***pocket (POC)*** *stem weight D=0.625 ounce (P=0.0001), stem length E=3.637 cm (P= 0.0001), total weight F=2.246 ounces (P= 0.0001), and stem count 771.5 stems (P= 0.0001), and* ***Konjac Gum (GUM)*** *stem weight G=0.192 ounce (P= 0.0001), stem length H=2.490 cm (P= 0.0001), total weight I=2.267 ounces (P= 0.0001), and stem count 123.9 stems (P= 0.0001)*

Based on these findings in relation to treatment, future investigations would not benefit from the application of the Konjac Gum treatment. The straight seed treatment confirmed that seed adherence with a food-grade adhesive is not necessary, and that it does not increase the overall output of the microgreens. The pocket treatment supported microgreen growth, but the stem removal process was more tedious than the straight seed treatment. The root and stem removal for the pocket treatment resulted in more coconut coir fiber pullout, resulting in increased mat degradation. The testing of the treatments in this study encourages the use of the straight seed technique for future investigations.

3.5.3 Trial

Based on statistical analysis, multiple trials are a good indicator for stem count success. Trial 4 has the best p-value (0.0001) and a t-ratio (5.51) out of all the trials. The increase in success as the trials progressed suggests that coconut coir mats have an increased productivity with repeated use. The stems, roots, and ungerminated seeds were removed from the mats and soaked in a vinegar and water solution after each trial. This was done to ensure that no roots, stems, or seeds were left over from previous trials to increase the overall stem count for each cycle. Due to human error, some seeds, stems, and roots could have been present after their designated trial. The fit mixed models in the data analysis would have accounted for this human error, ensuring that the increase in stem count for each trial was due to trial success and not residual germination.

Trial 1 had an average stem count of 372.222 stems, trial 2 508.056 stems, trial 3 900.889 stems, and trial 4 1061.389 stems. This gradual increase is significant for the reusability factor for coconut coir. The chart in Figure 3.27 represents the difference in the combined variables for each of the 4 trials. The chart depicts that trial 1 was the least successful across the recorded variable while trial 4 was the most successful trial. The correlation and fit mixed model analyses for trial confirmed this statistical significance. Trial 1 had a significant negative correlation in stem weight, stem count, and total weight. Trial 4 has a significant positive correlation in stem length, stem weight, and stem count which concludes that trial 4 was the most successful trial. The chart also presents a constant increase in stem weight, stem length, total weight, and stem count as the trials progress. This could lead to the interpretation that the coconut coir mats not only maintain germination and output for curly cress microgreens but increase in efficacy as the trials progress. The reusability of the material through multiple trials increases the sustainability of the entire system.

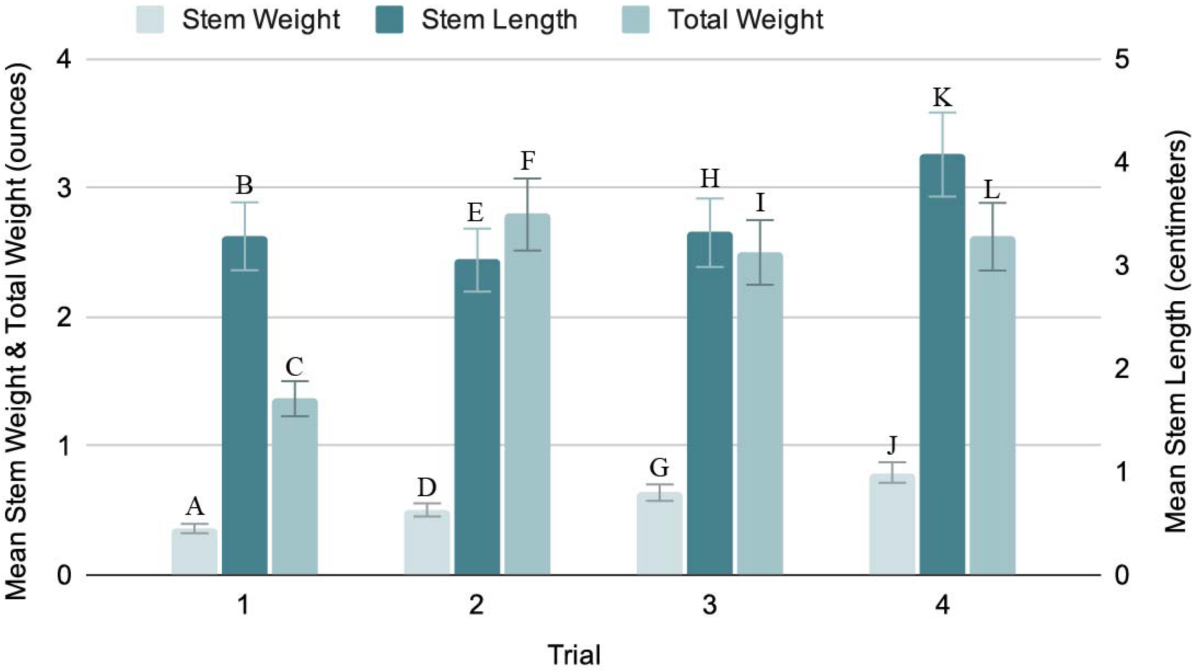


Figure 3.27: ***Trial 1*** *showing stem weight A=0.361 ounce (P= 0.0001), stem length B=3.282 cm (P= 0.0001), total weight C=1.367 ounces (P= 0.0001), and stem count 372.2 stems (P= 0.0001),* ***Trial 2*** *stem weight D=0.506 ounce (P= 0.0001), stem length E=3.052 cm (P= 0.0001), total weight F=2.794 ounces (P= 0.0001), and stem count 508.1 stems (P= 0.0001),* ***Trial 3*** *stem weight G=0.639 ounce (P= 0.0001), stem length H=3.315 cm (P= 0.0001), total weight I=2.500 ounces (P= 0.0001), and stem count 900.9 stems (P= 0.0001),* ***Trial 4*** *stem weight J=0.794 ounce (P= 0.0001), stem length K=4.073 cm (P= 0.0001), total weight L=2.622 ounces (P= 0.0001), and stem count 1061.4 stems (P= 0.0001)*

3.6 Discussion

The need for a food-grade adhesive as proposed by the study *Influence of Textile and Environmental Parameters on Plant Growth on Vertically Mounted Knitted Fabrics*, were proven to be unnecessary and even to have a negative effect on the germination rate and success of the microgreens. The addition of the Konjac Gum to the coconut coir samples led to a significantly lower stem length, stem weight, stem count across all the samples. This was surprising as it was expected that a secondary adhesive would be needed to assist seed adherence for germination. On the contrary, the straight seed treatment did have a significant effect on the stem length, stem weight, and stem count. This was unexpected as the treatment had the least amount of manipulation but resulted in the highest recorded variables.

Another unexpected aspect was the stem count increased as the subsequent trials progressed. Trial 1 began with an average stem count of 372.222 stems while trial four ended with 1061.389 stems. This 185% increase in stem count was surprising when a constant stem count was expected. This could be the result of the low exhaustion rate of coconut coir and its ability to resist mat degradation during the microgreen stem removal. Rather than just supporting a constant germination rate through the trials, the coconut coir mats have the ability to increase over time.

Based on the data analysis results, a future postulation could be when the coconut coir mat reaches its exhaustion level or does fiber pull-out ultimately render the mat unusable? Because of coconut coir's high lignin content, it is known for its durability and slow exhaustion rate. For this study, the germination rate increased linearly with trial repetition and fiber pull-out was rarely an issue. The stems were able to be easily removed by hand after soaking in water and vinegar overnight. Repeating this experiment until exhaustion of the material would be an interesting factor to investigate.

From the data and analysis presented in this chapter, coconut coir can grow curly cress microgreens in a vertical soilless system through multiple cycles.

CHAPTER 4: ARCHITECTURAL APPLICATION

4.1 Introduction

Currently, there are approximately 800 million hectares of land designated to soil-based farming globally, which constitutes about 38% of the total available land area (Kalantari, 2018). With the world population steadily increasing, the struggle for land allocation between food production and housing development will become increasingly evident. Innovative forms of green urban architecture aim to combine food production with architecture to produce food on a larger scale in urban areas such as rooftop gardens, rooftop greenhouses, indoor farms, and other building-related forms. Urban agriculture is currently considered one of the solutions to climate change adaptation (Specht, 2014). Agriculture could be introduced to architecture to save space and energy, while also reducing food scarcity in highly populated areas. In New York City, it is estimated that a 30-foot-tall building can provide food for 50,000 citizens (Despommier, 2009). This incorporation of architecture and agriculture forms a new urban relationship that can link food production and buildings for small-scale resource saving systems. Building integrated agriculture (BIA), as defined by Caplow, is the practice of high-performance hydroponic greenhouse systems on and in mixed-use buildings to exploit the synergies between the building environment and agriculture-like energy and nutrient flows (Caplow, 2009). Applications can include rooftop gardens, rooftop greenhouses, edible green walls, or even standalone structures like a pavilion.

This chapter introduces the development of a coconut coir knit textile to be used for the growth of microgreens on a GFRP rod pavilion structure. Preliminary research of lightweight structures was conducted for a deeper understanding of textile structure typologies, GFRP rods, and connection details. From this research, a pavilion was designed, and a module of the 5:1 scaled farming pavilion prototype model was constructed to analyze the potential of coconut coir as a media textile.

4.2 Structural Typologies

This study explores new ways of creating geometry, form, surface, and connections for deployable architecture using textile techniques and bent rod structures. A series of case studies, techniques, and details were examined, categorized, and hybridized to create a knowledge base for future investigations.

Typologies of basic textile techniques such as bundle, entwine, weave, and loop were chosen because of their abilities to create form, surface, and geometry. These traits were then identified in modern basket weaving or architectural applications to further study their individual connections, forms, and materials. Each project offered greater insight into the design, construction, and sequence of deployable architecture. An image of this categorization compilation can be seen in Figure 4.1.

4.2.1 Weave Typology

The two typologies from this study that showed promise were weave and loop. A weave is formed by interlacing long threads passing in one direction with others at a right angle to them to create a planar mesh. Weaves create a planar mesh by controlling the number and direction of threads. A standard plait weave consists of perpendicular warp and weft threads in a repetitive sequence to achieve a desired textile size. This pattern creates a self-bracing, shear resistant, geometrically controlled, and simply jointed textile structure. Because this technique does not depend on a single continuous thread, rather an additive process, a textile can be created for a variety of scales. The weaving pattern not only creates dimension, surface, and geometry, but also increases stability and form with the addition of directional threads.

4.2.2 Loop Typology

A loop structure is produced by a continuous thread that bends and crosses itself along a curve. The loop technique can be seen in a common knitting pattern, where only a single continuous member is needed to create a surface. This is advantageous because there is less material waste to produce the textile, unlike the weave technique. For knit textiles, all the yarn is used to create the loop pattern while the weave technique uses yarn to create the warp or vertical elements. When the woven textile is complete, the remaining warp yarn is cut from the loom and discarded whereas a knit textile is removed from the loom in its entirety. The looseness of the loop creates more flexibility and a range of motion than a weave pattern. A loop stitch, when pulled along its length and width, will stretch significantly compared to the tight pattern of the weave. The material characteristics for a weave pattern depend on the directionality of the warp and weft yarns for its flexibility. Knits also have the potential flexibility when pulled diagonally due to the directionality of the loop stitch. Although the loop typology is more flexible, a single break in the pattern can cause unraveling; unlike the weave pattern that can depend on stiff joinery of the warp and weft to maintain the surface.

4.2.3 GFRP Rod Connections

Connections are integral to maintaining tensile forces as the bent GFRP rods attempt to return to a neutral state. These connections not only maintain the overall deployable form but also allow for multiple GFRP rods to converge at a given point. Connections were examined for knowledge and inspiration for point connections to be used in future investigations. The connections studied varied in range of motion, stiffness, flexibility, and number of rods. The most promising connections that were chosen for further research had multiple rod connections, fixed range of motion, and high stiffness to maintain a tension structure. These connections create structural equilibrium without compromising the flexibility of the GFRP rod structure. The creation of a stiffening connection without compromising flexibility or directionality of the form was developed further in the following study.

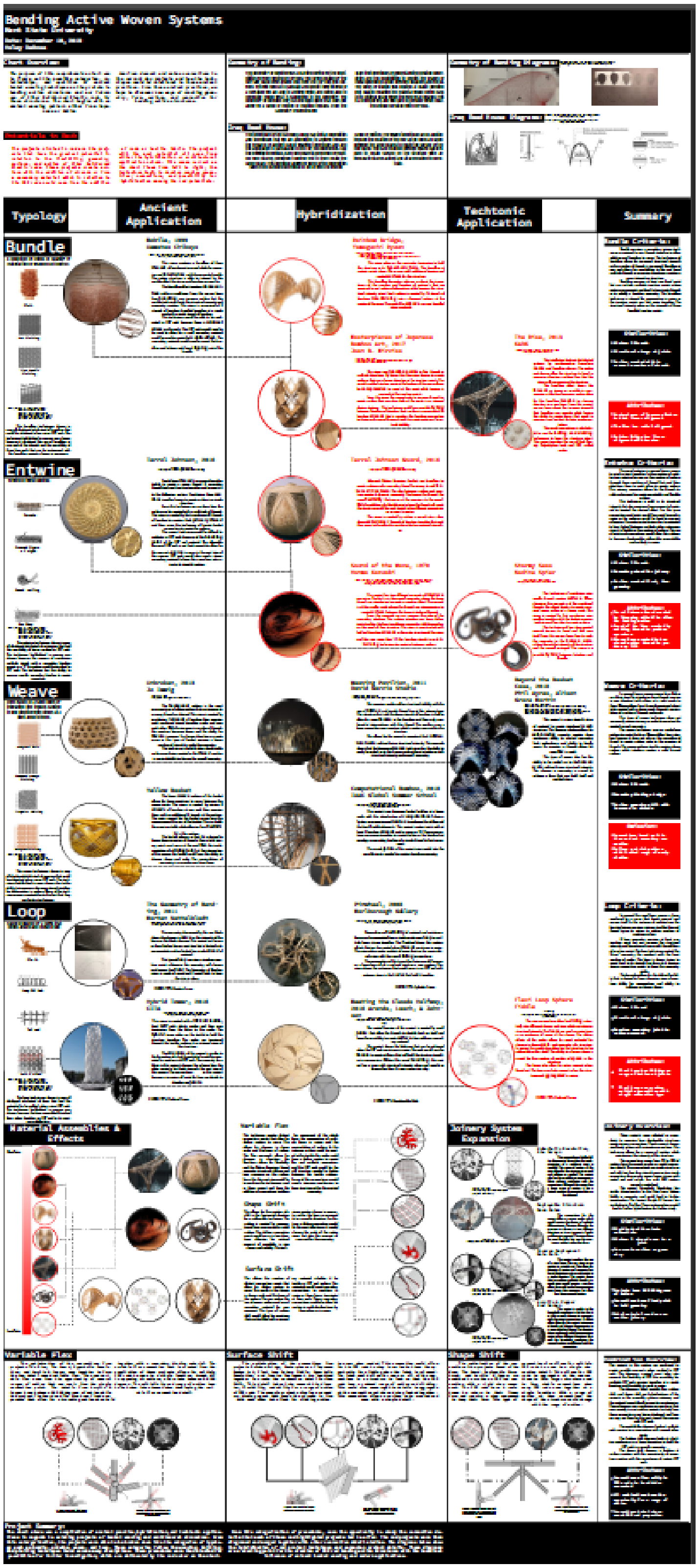


Figure 4.1: Bending Active Woven Systems Chart

4.3 Bending Active Tensile Structures

To design the farming pavilion for the architectural application portion of this thesis, bending active tensile structures were investigated. These structures refer to coupled systems of tensile bending-active components in which stiffness is gained through reciprocal stress dependency and elastic deformations of parental systems (Lienhard, 2015). The advantage of these structures is the ability to create complex free-form geometries from simple planar components (Slabbinck, 2019). These dynamic and adaptable forms derive from elastically deformed curved geometries prestressed by a lightweight membrane.

4.4 Set Up Study

Two textile techniques, knit and weave, were investigated for their efficacy in creating a soilless substrate for the germination of curly cress microgreens. Further information about the microgreen selection process for all experiments can be found in Appendix A - Curly Cress Microgreens. The two techniques were chosen because of their different thicknesses and stitch densities, as these factors have the potential to affect the germination and degradation of the textile. The thickness of the techniques may affect the potential root depth and attachment while the stitch density could affect the number of seeds that adhere to the textile surface. Samples were created for each of the techniques and tested in a growing tent for a seven-day trial. The textile with the greater germination rate was chosen for the final farming pavilion prototype model.

All the textile samples were created using Happy House Organic Garden Twine made of natural coconut coir fibers. The twine manufacturer advertised an ideal pH range of 5.5-6.5, water holding capacity three times the weight, biodegradability, and slow decomposition. The manufactured coconut coir twine was twisted with two strands of yarn with a total thickness of 13/64-inches (.51 centimeters). To decrease the overall thickness of the twine and for easier textile fabrication, the twine was soaked in warm water for twenty-four hours and then hand untwisted into a single strand of yarn with a diameter of 13/64-inches (.51 centimeters).

4.4.1 Knit Farming Textile

All the knit textiles in this study were created on an 11 ½ -inch (29.21 centimeters) hand knit loom with a knitting loom hook tool to create a looping figuration (Figure 4.2). A purl stitch was selected because of its simple but tight design (See Figure 4.3). Since only one trial was conducted, two 5-inch (12.7 centimeters) square coconut coir samples were created to ensure at least one sample had proper growth in the subsequent microgreen growth tests (Figure 4.4).

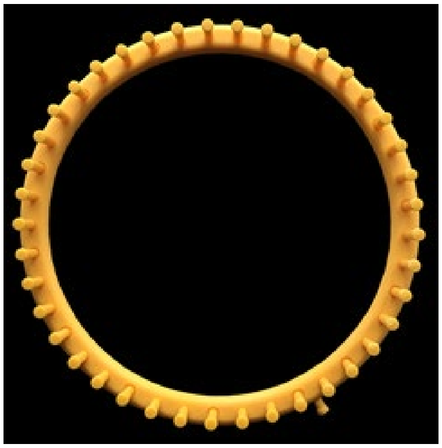


Figure 4.2: 11 ½ -inch hand knitting loom

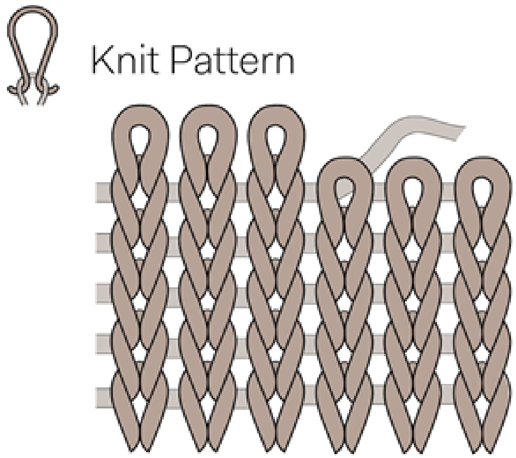


Figure 4.3: Purl knit pattern

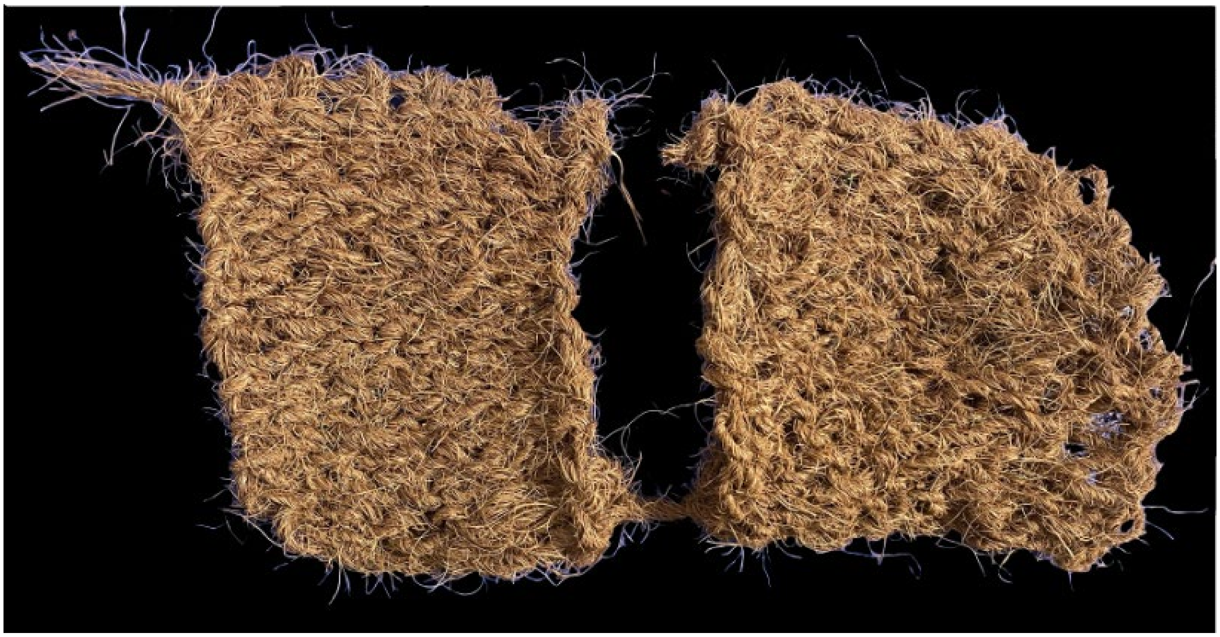


Figure 4.4: Two 5-inch square knit samples

4.4.2 Woven Farming Textile

The inspiration for a woven textile originated in preliminary research on bioinspiration textiles found in nature (See Appendix D- Bioinspiration). The weave samples were created on a handmade, cardboard loom frame with dimensions of 10-inch by 7-inch (25.4 x 17.78 centimeters) with eleven 1-inch by 1-inch (2.54 x 2.54 centimeters) slits cut into the long dimension (Figure 4.5). A standard perpendicular weave pattern was chosen because of its simplicity (Figure 4.6). The longitudinal cardboard slits support the warp yarn, while the transverse weft yarn is drawn through and inserted over-and-under the warp (Figure 4.7).

Figure 4.5: Weave frame with warp yarn applied

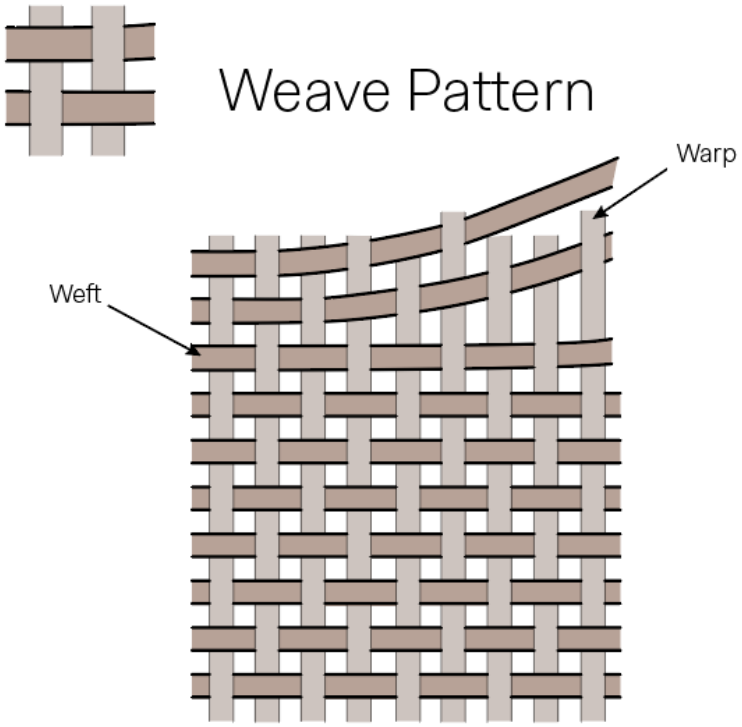


Figure 4.6: Weave pattern diagram

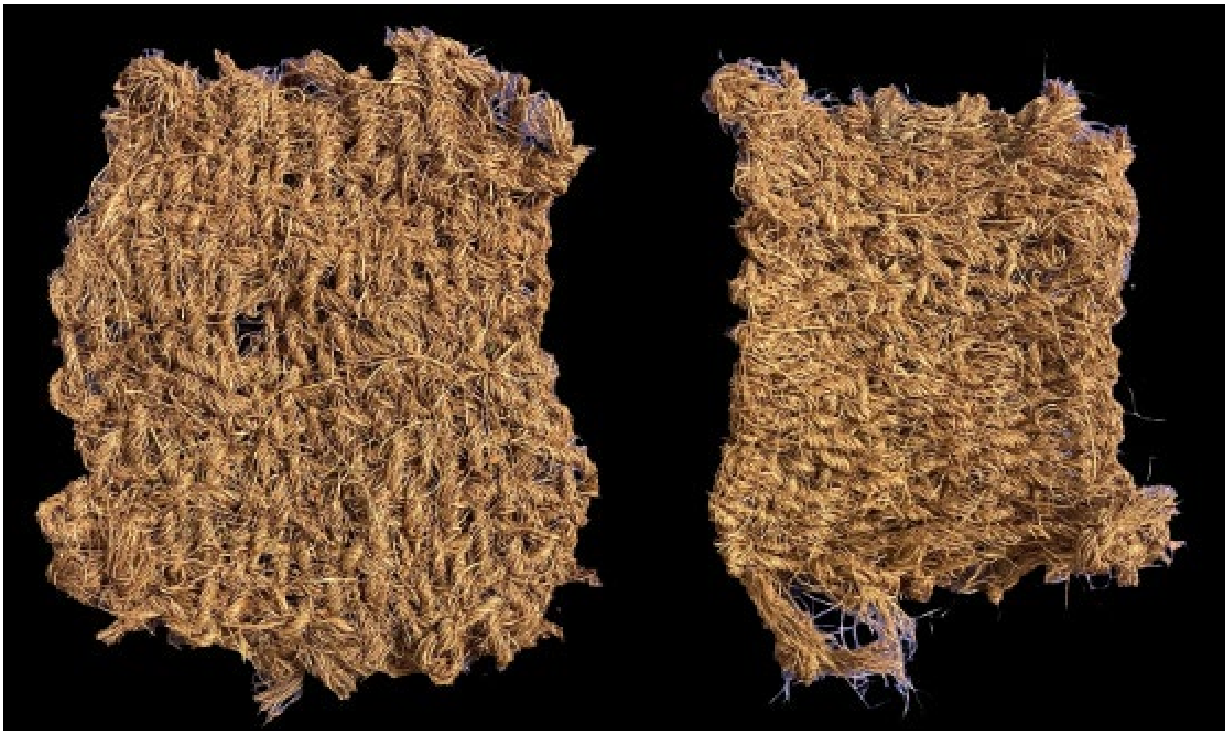


Figure 4.7: Two 5-inch square weave samples

4.4.3 Knit versus Weave Growth Study

All the growth tests in this study were carried out in Room 023 NEDlab of the College of Architecture and Environmental Design in Kent, Ohio. The NEDlab contains a 30-inch by 30-inch by 60-inch (76.2 x 76.2 x 152.4 centimeters) Lighthouse Hydro growing tent, 135-Watt Black Dog LED light (BDmicro-U), and a thermometer/humidity gauge (Figure 4.8).

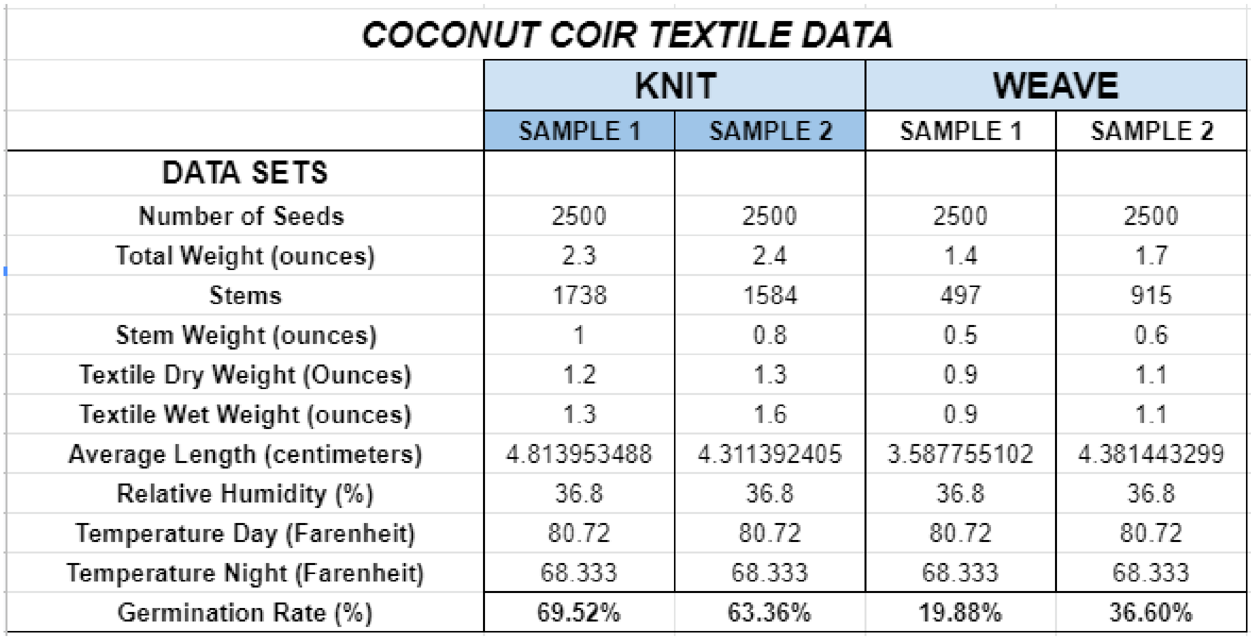
Figure 4.8: Growing tent setup with samples conducted between November 1st through 7th of 2020

To apply the microgreens, the coconut coir textiles were placed on a flat surface, sprayed with water until saturated, and then two thousand five hundred seeds were spread over one side of the sample surface. The seeds and coconut coir samples were again saturated with water to activate the mucilaginous seed gel coating. This gel coating lowers water intake during germination and encourages adherence to the textile when exposed to water. The samples were then hung inside the growing tent with string and clips.

To reach their full germination cycle, the coconut coir textiles were left in the tent for seven days. The samples were exposed to the Black Dog LED light for 12 hours each day and watered by hand with a spray bottle twice a day for the duration of the trial. Samples were only removed from the tent to take pictures at the end of each day to record growth.

4.4.4 Knit versus Weave Growth Study Results

Data was collected during the trial and recorded for the two knit and two weave textile samples (Table 4.1). These data sets include number of seeds, total weight, stem count, stem weight, textile dry weight, textile wet weight, average length of stems, tent relative humidity, tent temperature, and germination rate. The knit textile had a greater total weight, stem count, stem weight, textile dry weight, textile wet weight, and average length. The knit textiles also had a much higher germination rate between 63.36% and 69.52% while the weave textiles had germination rates between 19.88% and 36.60% (Figure 4.9). Since the knit textile samples presented higher germination rates, they were selected for the farming pavilion prototype model.



COCONUT COIR TEXTILE DATA	KNIT		WEAVE	
	SAMPLE 1	SAMPLE 2	SAMPLE 1	SAMPLE 2
DATA SETS				
Number of Seeds	2500	2500	2500	2500
Total Weight (ounces)	2.3	2.4	1.4	1.7
Stems	1738	1584	497	915
Stem Weight (ounces)	1	0.8	0.5	0.6
Textile Dry Weight (Ounces)	1.2	1.3	0.9	1.1
Textile Wet Weight (ounces)	1.3	1.6	0.9	1.1
Average Length (centimeters)	4.813953488	4.311392405	3.587755102	4.381443299
Relative Humidity (%)	36.8	36.8	36.8	36.8
Temperature Day (Farenheit)	80.72	80.72	80.72	80.72
Temperature Night (Farenheit)	68.333	68.333	68.333	68.333
Germination Rate (%)	**69.52%**	**63.36%**	**19.88%**	**36.60%**

Table 4.1: Knit and weave sample data

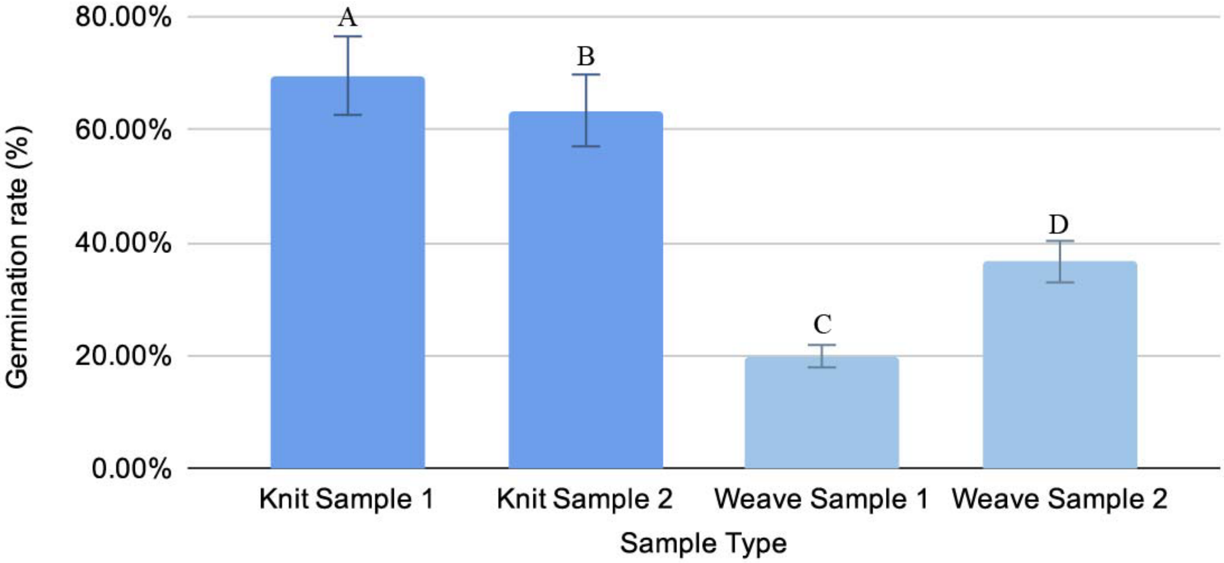


*Figure 4.9: Knit versus weave germination rate showing **knit sample 1** A=69.52), **knit sample 2** B=63.36%, **weave sample 1** C=19.88%, **weave sample 2** D=36.60%*

4.5 Method

Investigations began by designing a three-dimensional model at the architectural scale in Rhinoceros 6. The model consisted of two modules aggregated together to create a square farming pavilion design. The simple modular design was chosen because of the ability to expand with the inclusion of additional modules. The full-scale digital model was designed to support panels large enough to provide ample shading, shelter, activity space, and food production when aggregated together in a simple configuration. The full-scale model had dimensions of 27-feet by 22 ½-feet with six 12-feet by 12-feet triangular knit textile panels and two 4-feet by 13 ½-feet panels at the base. This model was used as the basis for the 5:1 scale physical farming pavilion prototype that tested the growth of curly cress microgreens.

The farming pavilion prototype model materials included ¼-inch (0.635 centimeter) glass fiber reinforced plastic (GFRP) rods, 3/32-inch (0.238 centimeter) coconut coir yarn, PLA 3D print material, and curly cress microgreen seeds. The GFRP rods were chosen because of their form-active system. The physical farming pavilion prototype model consisted of one module of the digital design so that it could fit within the dimensions of the growing tent. The digital model was originally designed for the textiles to act as a tensioning piece within the structure but upon modeling the prototype, the textiles in fact did not act as a tensioning element. The textiles in the prototype had no structural forces applied other than the weight of the microgreen plants and water.

The knit textiles used for the 5:1 scale farming pavilion prototype were created with the same loom equipment, coconut coir yarn, and purl stitch stated in section 4.3.1 Knit Farming Textile. However, these knit textiles differed in shape and dimension from those created in section 4.3.1

Knit Farming Textiles. For the farming pavilion prototype model, three 15-inch by 15-inch by 22-inch (38.1 x 38.1 x 55.88 centimeters) triangular, and one 4-inch by 24-inch (10.16 x 60.96 centimeters) rectangular textiles were created. To create the triangular textiles, a new stitch was cast onto the circle loom every second row to increase the size of the textile and achieve the desired shape.

4.5.1 Farming Pavilion Design

The full-scale digital model with two modules aggregated together contained six panels that were arranged in a square within the 27-foot x 27-foot (822.96 x 822.96 centimeters) boundary. The modules were aggregated into a square with two sides containing two triangle textiles and the other two sides had one triangle textile. This created two openings to the interior of the structure for light and air to enter (See Figure 4.10).

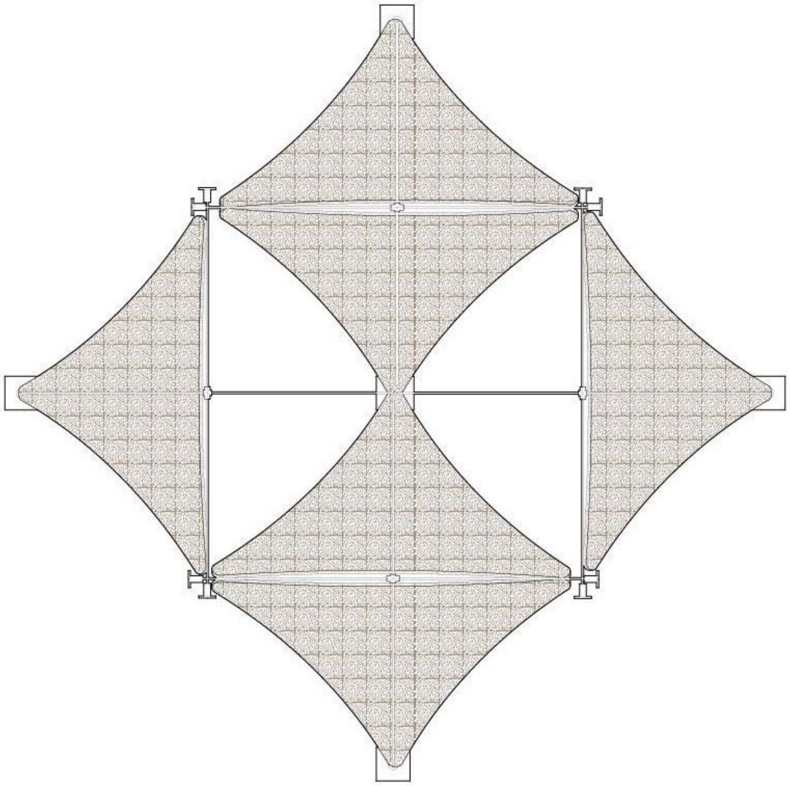


Figure 4.10: Top view of farming pavilion showing openings

Four main tension arches with a span of 13 ½-feet (411.48 centimeters) and a height of 22 ½-feet (685.8 centimeters) and a diameter of 1 ¼-inch (3.175 centimeters) each were placed in a 90-degree cross with a central anchor point. The main arches were supported by footers on each side of the cross. A 14-foot (426.72 centimeters) rod spanned from each of the outer footers to the central footer to maintain the shape of the arches. This central anchor can be seen in the elevation (Figure 4.13) and section (Figure 4.12). The textile panels were supported on the tension arches with a series of three supplementary rods to maintain the fabric's shape. The first tension rod spanned from the edge of the triangle textile, through the center of the main tension arch, to the other end of the long side of the triangle textile. This holds the tips of the triangular textile at the same height as the top of the tension arch. The third end of the triangular textile was anchored to the side of the main tension arch with a textile spacer. The configuration of the supplementary rods can be seen in the section drawing in Figure 4.12.

To harvest the plants at the end of the growth cycle, the triangular panels would need to be removed from the structure. Once off the structure, the plants and roots would be removed and the panels soaked in a vinegar and water solution to eliminate roots, stems, and any remaining ungerminated seeds. This would ensure that bacteria would not hinder subsequent growth cycles. The panels would then be reattached to the pavilion structure for continued plant growth.

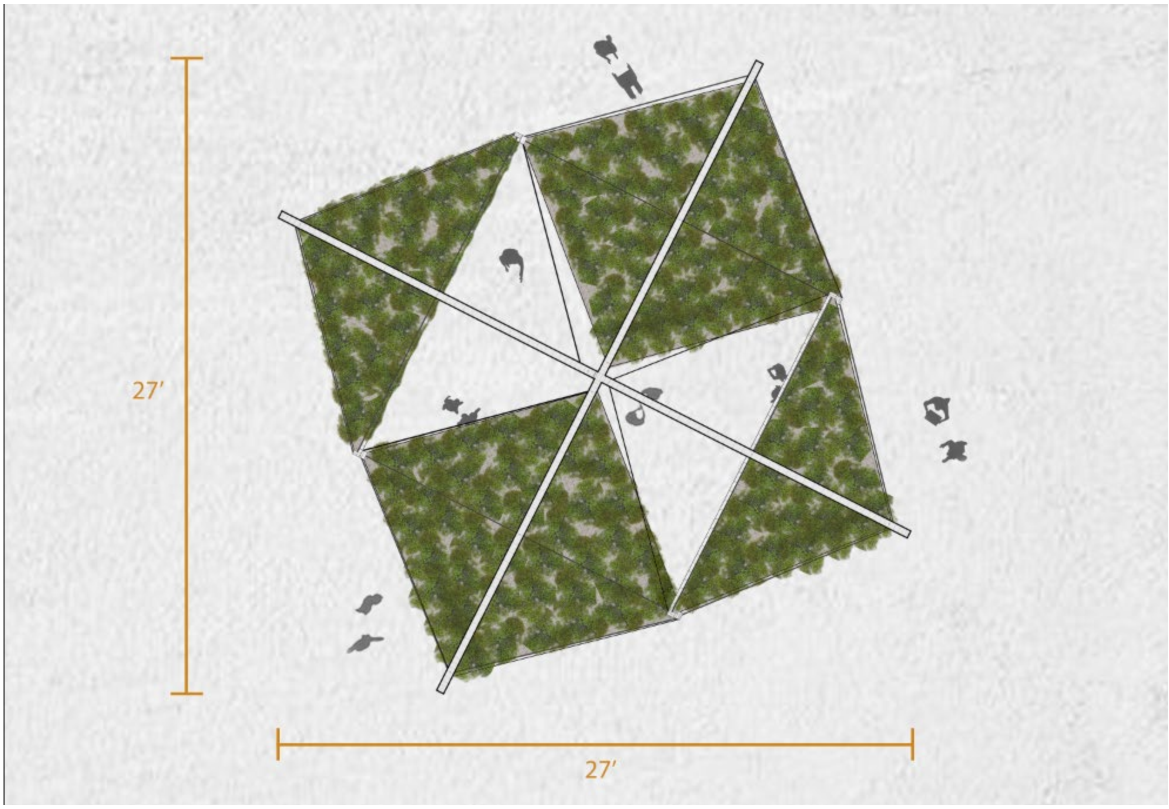


Figure 4.11: Architectural plan of the pavilion

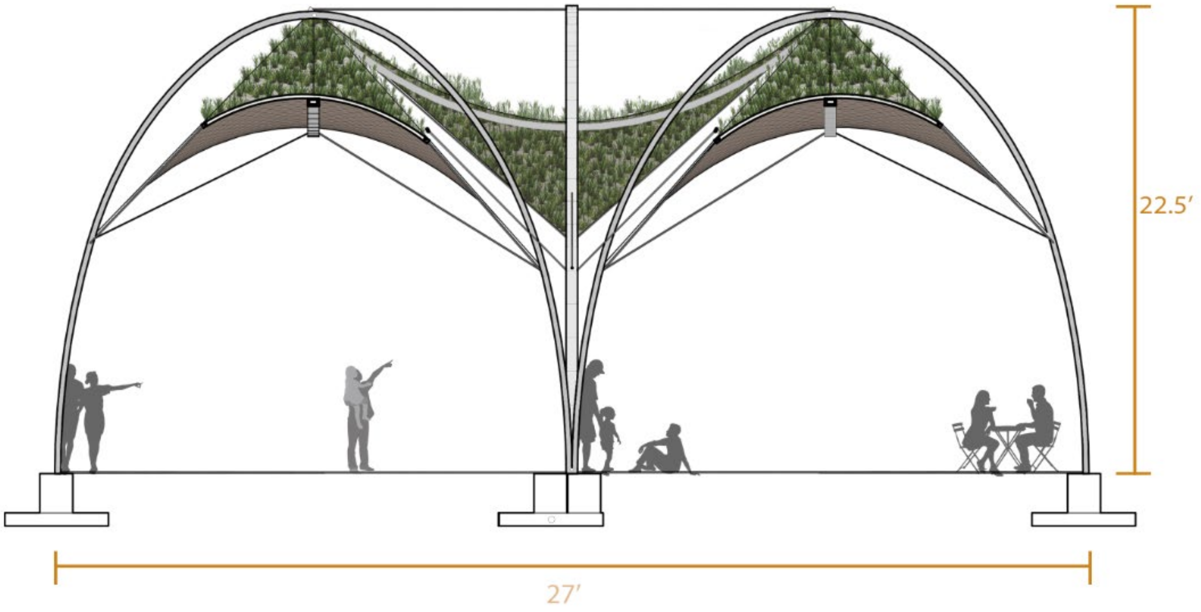


Figure 4.12: Architectural section of the pavilion

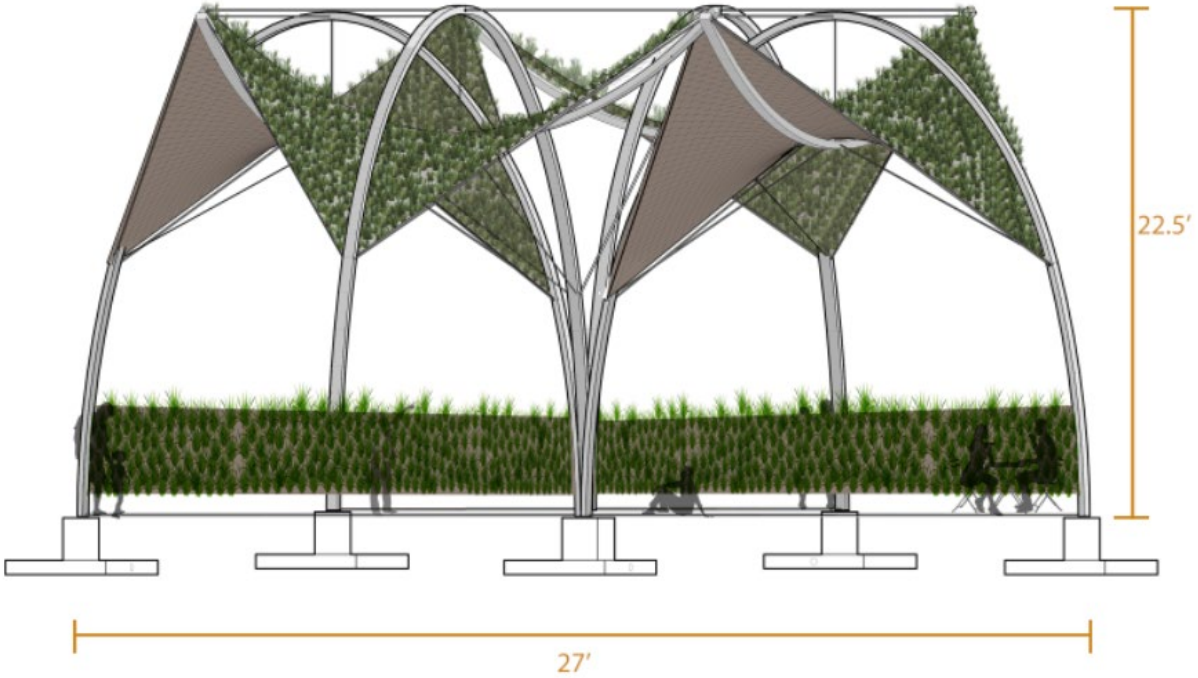


Figure 4.13: Architectural elevation of the pavilion

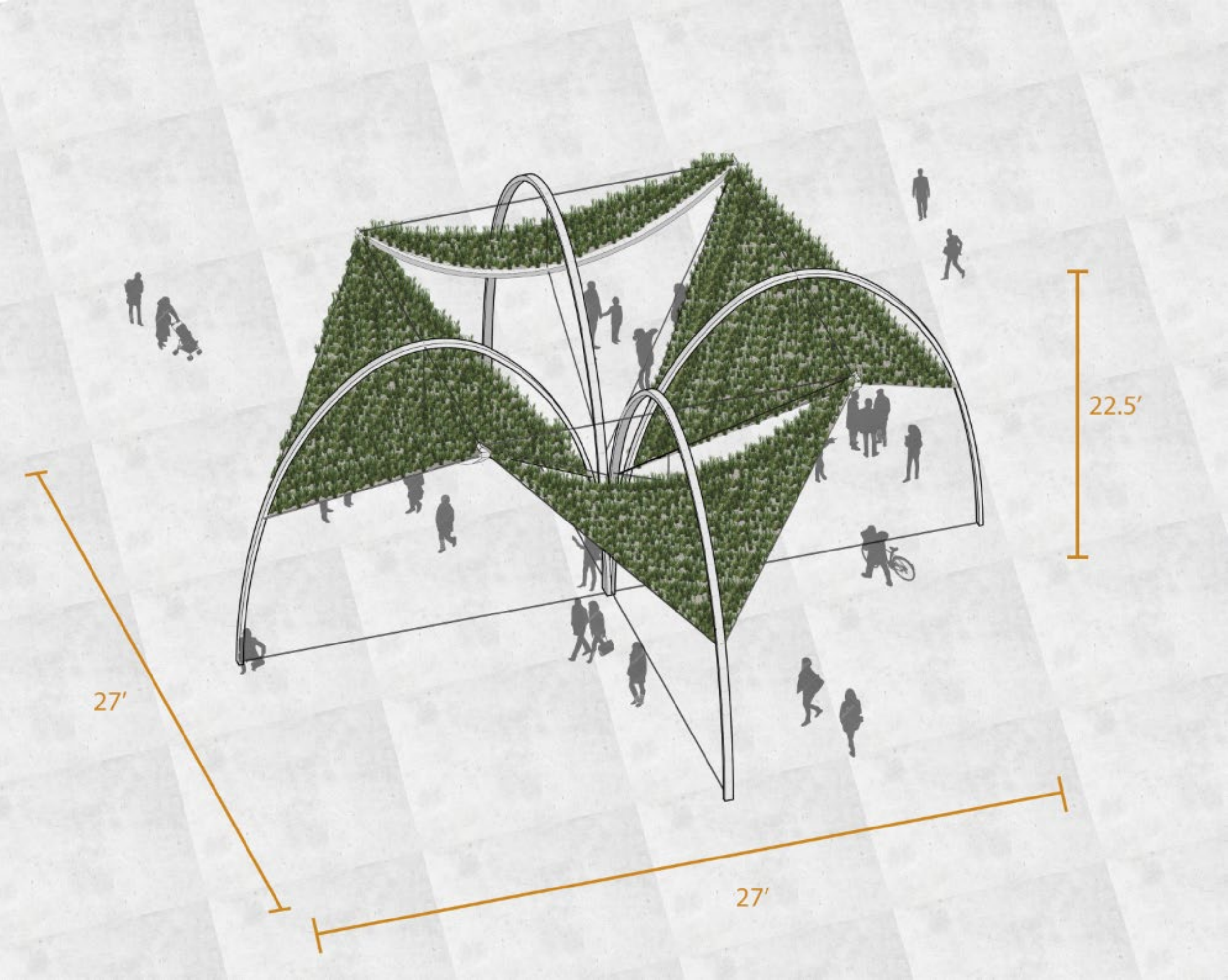


Figure 4.14: Architectural axon of the pavilion

The three-dimensional design of the pavilion was then used to create a 5:1 scale farming pavilion prototype model. Differences in the tensile forces on the textile for the prototype model were found and discussed in the subsequent sections.

4.5.2 Farming Pavilion Prototype

Once the farming pavilion was designed, the connection pieces for the farming pavilion prototype model were digitally built in Rhinoceros 6 and printed on a Creality CR-10 3D printer. The footers were designed to hold the weight of the structure, microgreen dead load, and water load during germination with the least amount of PLA printing material possible to maintain a lightweight structure (see Figure 4.15). The infill of the printed connections was increased to account for the force of the bent GFRP rods in tension.

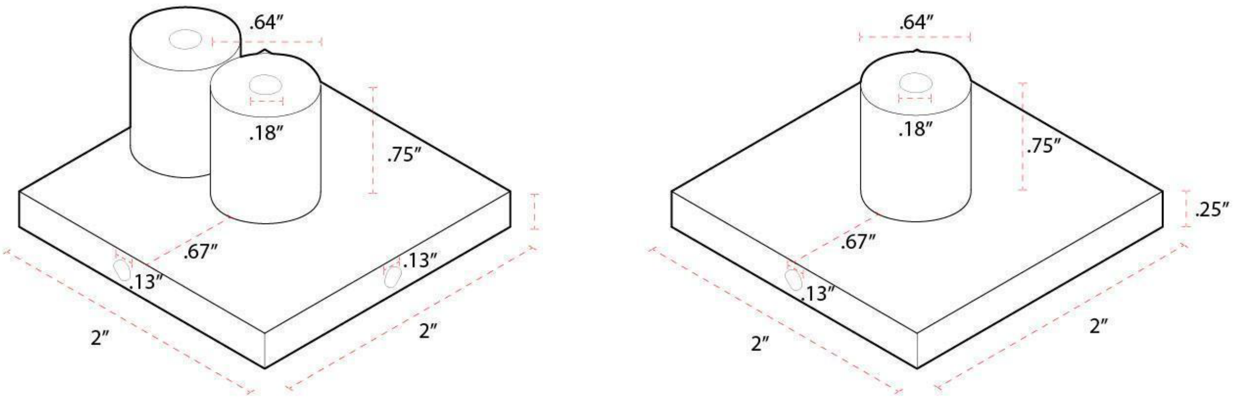


Figure 4.15: Double footer (left) and single footer (right) with dimensions

Textile spacers were developed to hold the knit media in place and support a supplementary rod that extends from the connector at the center of the textile to the edge of the tensile arch. This piece was designed to slide onto the GFRP arch and maintain a position 7-inches (17.78 centimeters) above the footer. A hole was placed on the side of the textile spacer to hold the supplementary rod spanning from the connector at the apex of the arch (see Figure 4.16).

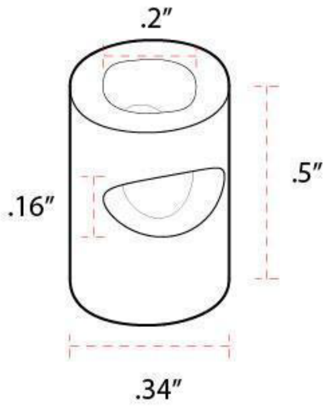


Figure 4.16: Textile spacer with dimensions

A connector was designed (see Figure 4.17) for the apex of the tension arch to thread the supplementary rod supporting two corners of the textile. This piece ensures the supplementary rods stay in place and maintain a perpendicular orientation to the arch (see Figure 4.18).

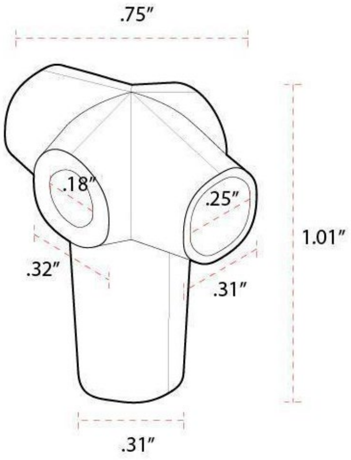


Figure 4.17: Connector with dimensions

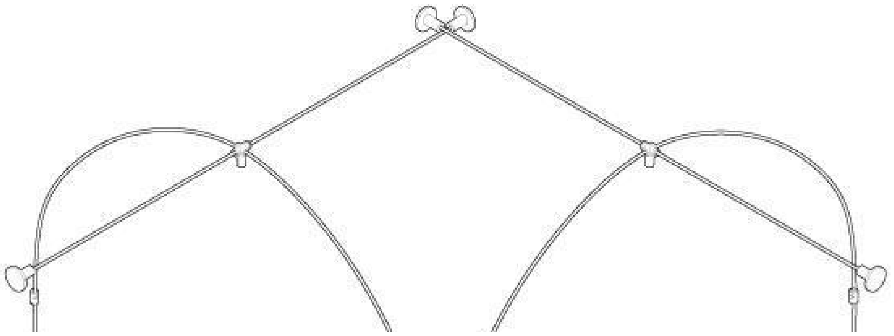


Figure 4.18: Supplementary rod through connectors

To assemble the base of the farming pavilion prototype model, two 22-inch (55.88 centimeters) GFRP rods were inserted into the holes of the double footer at 90-degree angles. The two single footers were then placed at the end of each 22-inch (55.88 centimeters) base rod to tension the bottom of the arch (see Figure 4.19). With this positioning, both arches create a right angle with the double footer being the centroid.

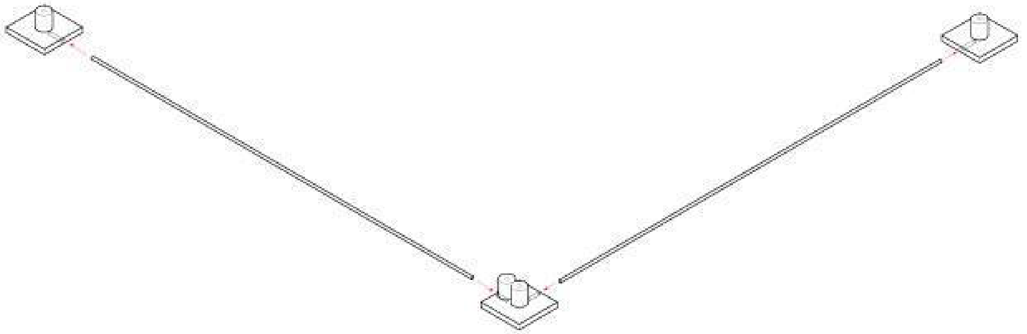


Figure 4.19: 22-inch GFRP rods placed in footers

The main tension arches were assembled by sliding and positioning the textile spacers and connectors onto the 36-inch (91.44 centimeters) GFRP rods. The connector was positioned at the midpoint of the rod and the textile spacers were placed 7-inches (17.78 centimeters) from each end (see Figure 4.20).

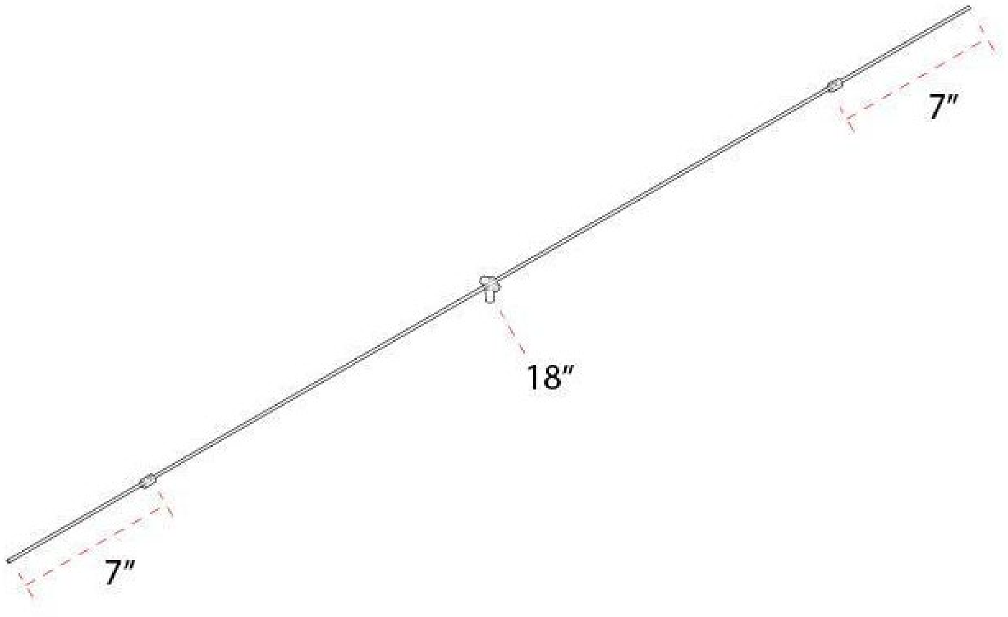


Figure 4.20: GFRP rod with two spacers and one connector

Once the spacers and connectors were added, one end was placed into the double footer (see Figure 4.21) then bent into the perpendicular single footer (see Figure 4.22). This created the main tension arches for the structure.

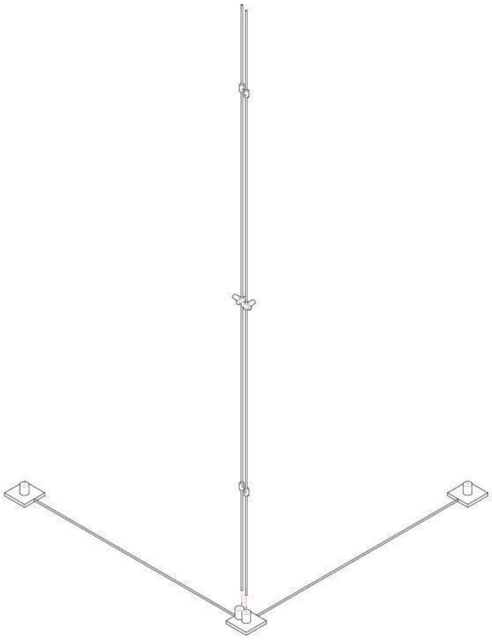


Figure 4.21: Placing 36-inch GFRP rods into double footer

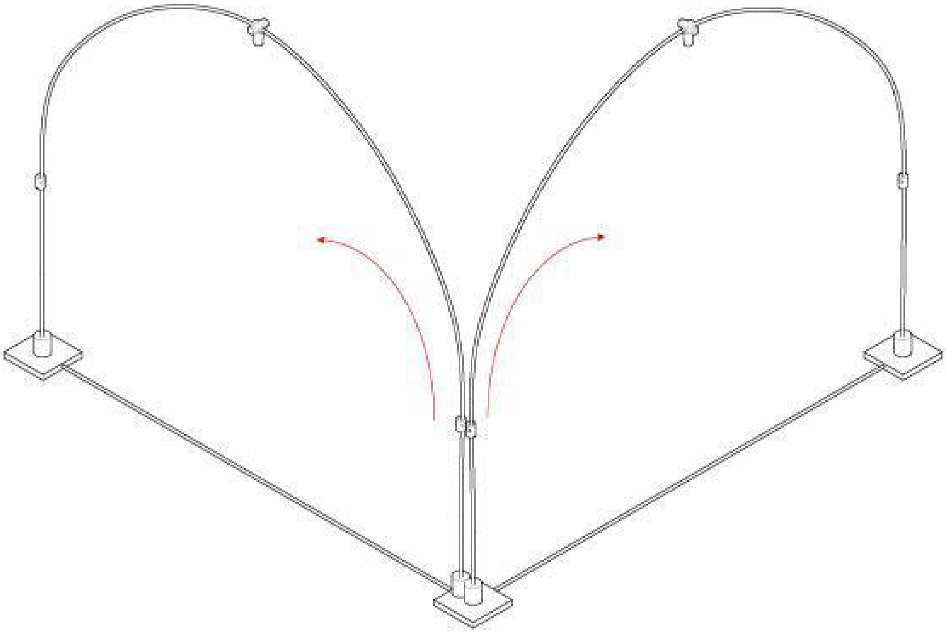


Figure 4.22: Bending 36-inch GFRP rods to place in single footers

Two 24-inch (60.96 centimeters) GFRP rods were threaded through the connectors at the apex of the tension arches to support the triangle knit textile (see Figure 4.23).

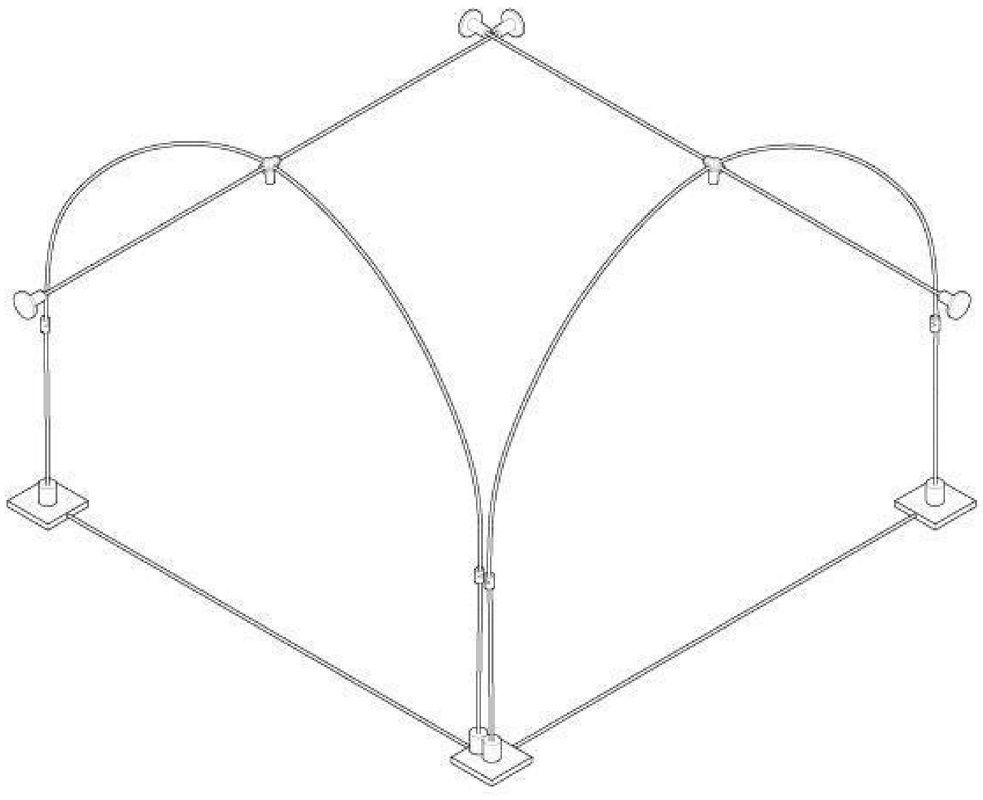


Figure 4.23: 24-inch GFRP rods threaded through connectors

To stiffen the tension arches, four 16-inch (40.64 centimeters) GFRP rods were placed diagonally from the connector at the apex of the arch to the textile spacers 7-inches (17.78 centimeters) above the footers (see Figure 4.24).

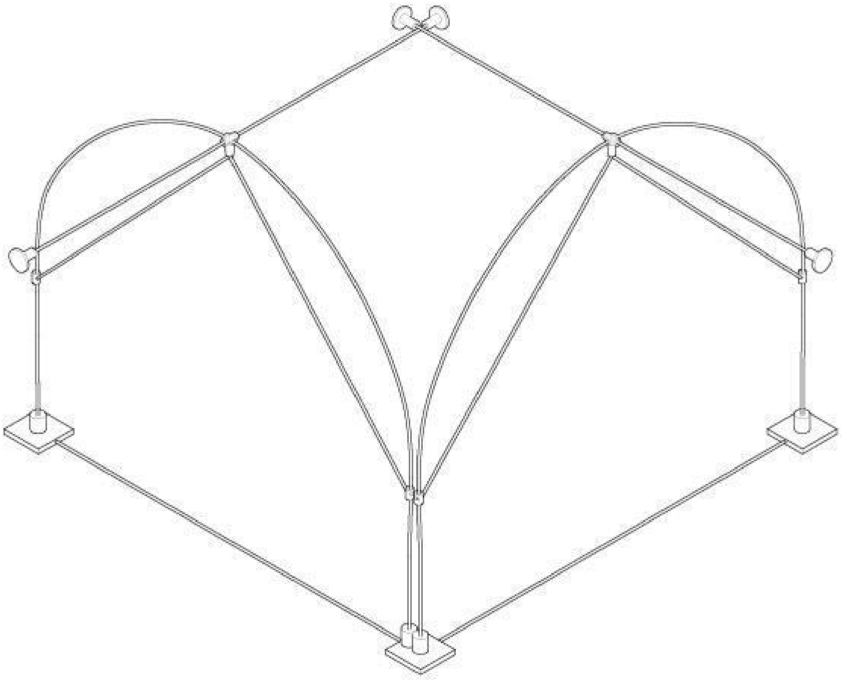


Figure 4.24: Four 16-inch GFRP rods added for stability

Once the frame was constructed, the triangular knit textiles were attached to the structure. One corner of the textile was threaded through the 36-inch (91.44 centimeters) tension rod until it reached the textile spacer 7-inches (17.78 centimeters) above the footer. The other two corners of the textile were threaded through the ends of the 24-inch (60.96 centimeters) horizontal GFRP supplementary rod at the apex of the tension arch. Two 3D printed caps were placed on the ends of the 24-inch (60.96 centimeters) GFRP rods to keep the textile from sliding off. This process was repeated two more times to attach the second and third knit textile to the structure. The rectangular knit textile was attached to the textile spacers on either side of the tension arch (see Figure 4.25).

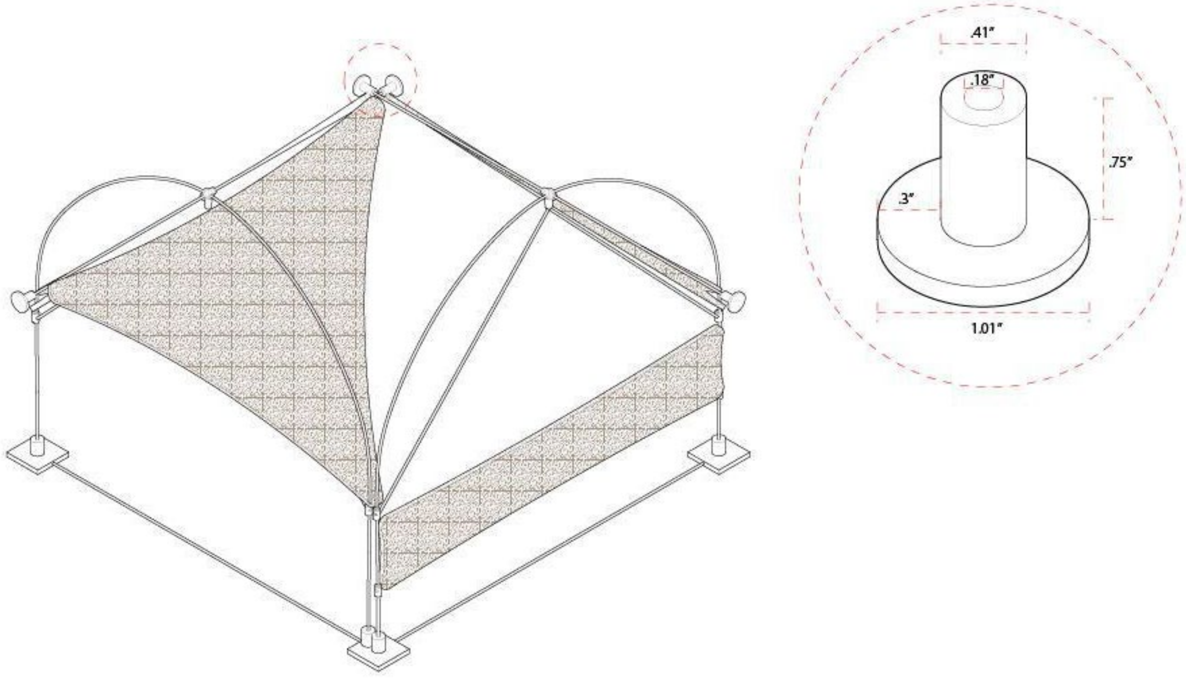


Figure 4.25: Coconut coir knit textiles added to frame with cap detail

All the pieces and final assembly of the physical model can be seen in Figure 4.26.

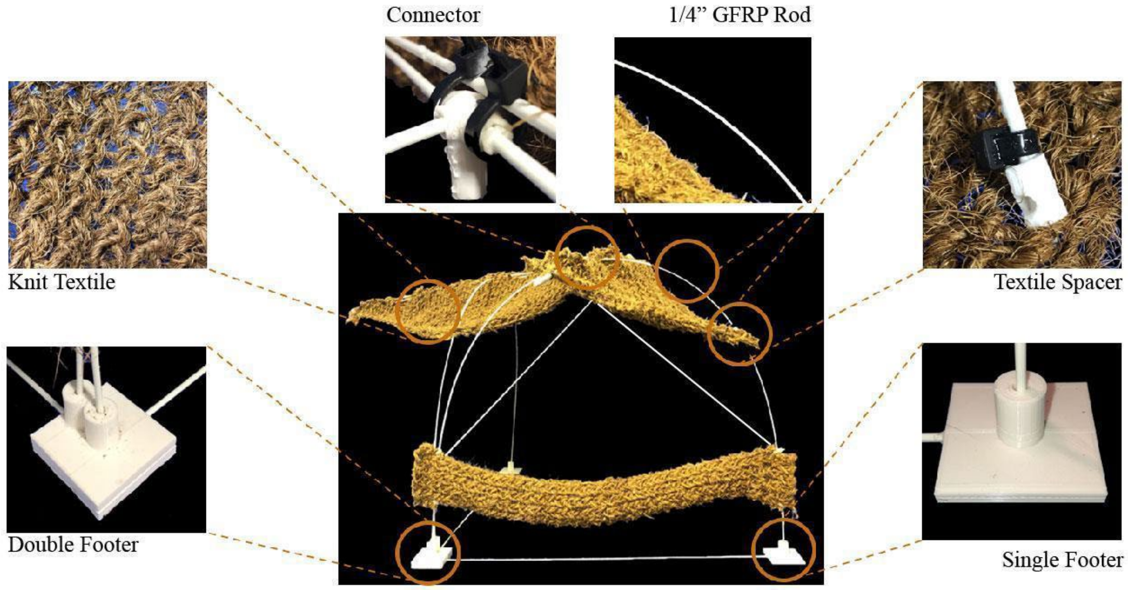
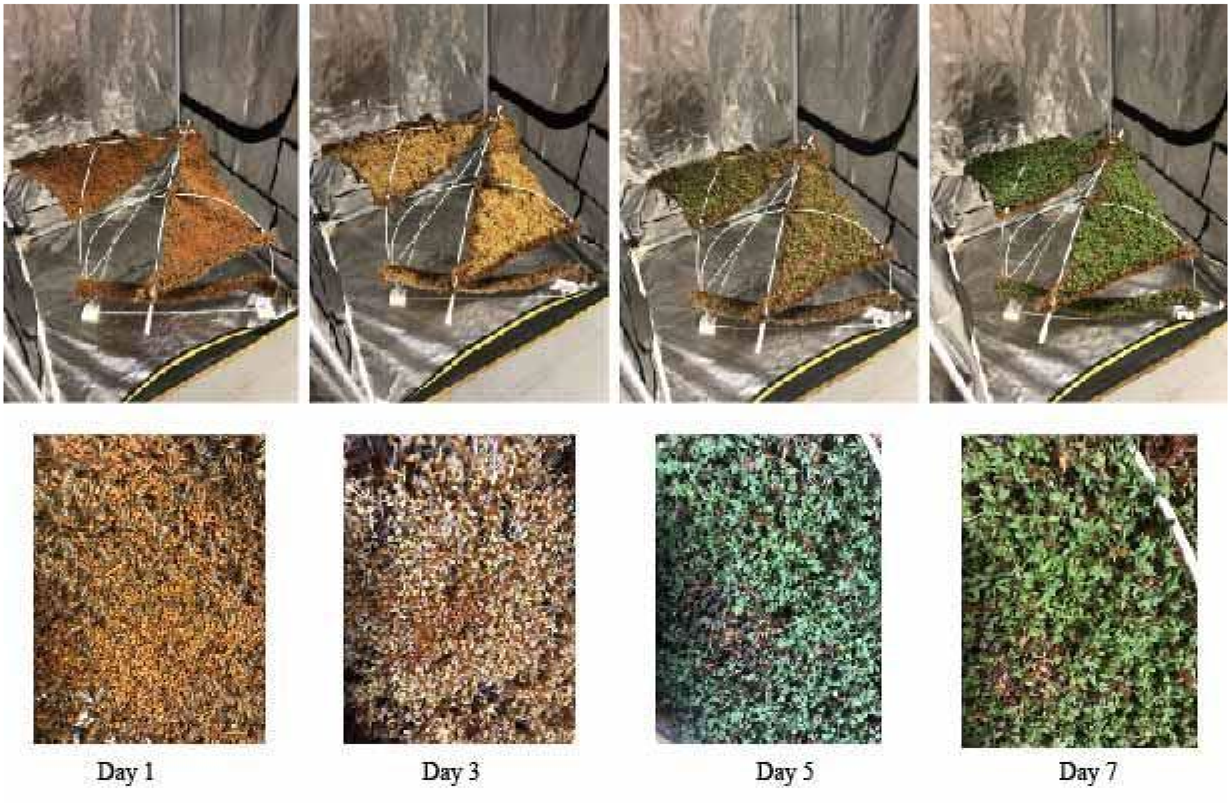


Figure 4.26: Prototype pieces and final assembly

4.6 Farming Pavilion Prototype Growth Observation

The farming pavilion prototype growth observation was conducted in room 023 NEDLab under the same environmental conditions and equipment previously mentioned in section 4.3.3 Knit versus Weave Growth Study. This experiment differed from the Knit versus Weave Growth Study by implementing a knit textile and an increased number of curly cress microgreen seeds. In the previous knit and weave studies 2,500 microgreen seeds were used for 25 inch^2 (161.29 cm^2) of surface area. This study applied 16,500 microgreen seeds for 165 inch^2 (1064.51 cm^2) of surface area; a 5:33 ratio to the previous studies. Consequently, 9,600 curly cress seeds were applied to the 4-inch by 24-inch (10.16 x 60.96 centimeters) knit textile based on the same principle. The farming pavilion prototype growth observation also does not use a pocketing technique or Konjac Gum Powder, as a straight seed application was shown to be the most effective.

Once all seeds were applied to the knit textiles, the entire structure was hand watered with a spray bottle to ensure seed and textile saturation. The farming pavilion prototype was then placed inside the growing tent for the next seven days. The structure was exposed to the grow light for twelve hours and watered twice a day by hand with a spray bottle. Images were taken at the end of each day to document the growth process. Images from day 1, 3, 5, and seven can be seen in Figure 4.27. All four of the knit textiles achieved microgreen growth over the entirety of the surface (Figure 4.28). The structure was also able to withstand the added weight of the microgreen sprouts and water saturation after seven days.



Day 1

Day 3

Day 5

Day 7

Figure 4.27: Prototype inside growing tent

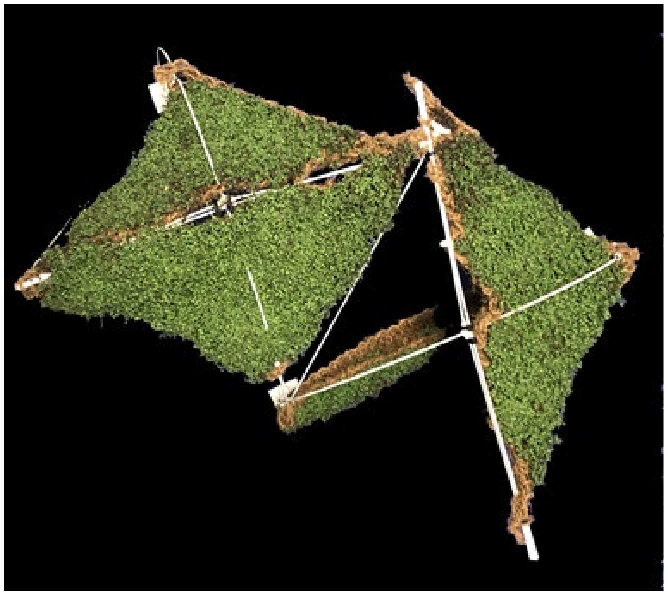


Figure 4.28: Prototype top view at end of germination cycle

4.7 Discussion

The farming pavilion prototype model displayed successful germination and growth of curly cress microgreen on the lightweight GFRP structure in the observation study. Although the pavilion was able to withstand the weight of the microgreen sprouts and water saturation at the end of the seven days, there is limited proof that this would be achievable at the architectural scale described in the digital model drawings in Figure 4.11-4.14. The added dead loads of the water and microgreens were not calculated prior to constructing the model. At the architectural scale, these factors would result in a constant change of weight that could potentially compromise the structure. Water and microgreen dead loads would also need to be considered for the dimensioning of the primary structure. The larger the area of the pavilion, the more the dead load will affect the overall structure, resulting in more supports. The added dimension of plant growth would also change how natural forces like wind would affect the integrity of the structure. These were not accounted for in this observational study and would need further calculations for proof of concept.

As previously mentioned, the textile was designed to participate in the tension of the entire structure but upon physically modeling the pavilion, the textiles had no structural role. The textiles hung on the structure while the printed footers and the rod that spanned between them provided the necessary tension forces to maintain the bent GFRP rod arches. From the physical model results, it is unclear whether the coconut coir knit textiles would have been able to withstand the tension forces on the bent GFRP rods. The stiffness of the material is also a factor that would influence the tensile strength of the textile. The textile had the strength to support the weight of the microgreen growth but if tension forces from the structure were applied, the textile could have potentially failed. Further material studies would need to be conducted to ensure that the coconut coir textile could withstand the forces present in the pavilion model.

Additionally, the coconut coir yarn used in the farming pavilion prototype is not the proper scale. The smallest diameter of coconut coir yarn available is 3/32-inch (0.238 centimeter), which is larger than the 1/64-inch (0.040 centimeter) diameter needed to be proportional to the farming pavilion prototype scale model. This could lead to the assumption that the coconut coir media textile created for the farming pavilion prototype model has a greater capacity because of its increased dimension. According to Jeffrey Delarue, coconut coir has an average tensile strength of 18.2 N and an average tensile stress of 117.46 MPa (Delarue, 2017). Coir fibers derived from the husks are unusually ductile, with an elongation of more than 20% in tension, which gives the husks a large energy absorbing capacity on impact. This is remarkably better than most natural fibers which have an elongation of 1-2% in tension. This postulates that of the available natural fibers, coconut coir has the highest potential for tension textile creation. The knitted structure would add to the flexibility of the textile system. The flexibility of the coconut coir textile allows for the creation of double curvature geometries, causing controlled deformation of the surface. This could be investigated through thorough computational modeling of the textile and structure. Deeper material and structural investigations would need to be conducted to prove that coconut coir has the tensile strength to be deployable at full scale for a GFRP form active system. The integration of the coconut coir media textile into the structure could lead to new hybrid structure systems. This would allow the textile to not only be load-bearing for the microgreen growth but also stabilizing for the entire system.

Because the structural capacity of the textile is unknown, there may be a need for a structural component within the coconut coir textile to increase stiffness and tensile strength. Including

GFRP rods into the textile like boning could supplement the textile tensile strength and form retention while also decreasing sagging. This would reduce the stress on the brittle textile without drastically altering the form expression of the structure.

4.8 Summary

This study showed strong potential for the creation of a coconut coir media textile on a lightweight GFRP form active architectural structure. Although this model is hypothetical, the hypothesis frames a direction for future work and application. It is important for more application of coconut coir textiles to be investigated along with the necessary calculations. Studying the individual elements, calculations, and applications can inform the future of food production and space creation.

The availability of coconut coir yarn proved to be limiting in creating the media textile. In the digital model, the textile was designed to tension the structure along with the footers and connections. This study could be enriched by creating a sample textile at full scale to truly study the textile’s capacity. This would allow for investigations and calculations into the tensile properties of the coconut coir textile that were not able to be completed. Applying the textile in true tension could lead to an interesting investigation between elasticity and rigidity of a form active pavilion.

Future research into the growth of a variety of different plants on the farming pavilion would be interesting. Microgreens grow quickly and are lightweight which was advantageous for this study but plants with more complex root structures, weights, and environmental needs would be compelling to test on the coconut coir textile. This could not only test the root adherence capabilities of coconut coir textiles but also the weight capacity.

CHAPTER 5: COCONUT COIR AS A SOILLESS MEDIA & THE IMPACT ON ARCHITECTURAL APPLICATIONS

The purpose of this experimental and observational analysis is to examine the efficacy of coconut coir to support vertical microgreen growth and its ability to be crafted into a soilless media textile for an architectural application. This chapter includes a summary of pertinent literature and findings regarding coconut coir, soilless systems, and experiment treatments. It then discusses the significant findings of the germination study analysis through graphs, coconut coir textiles creation, and the developing questions that can arise when used in a deployable structure.

5.1 Summary of Research

This thesis investigates the use of coconut coir as a sustainable soilless media for vertical growth systems. The study began with a series of four germination studies for two brands of commercial coconut coir mats. The results from these trials led to the creation and comparison of knit and woven coconut coir media textile samples. Experiments were conducted to test the viability of the knit and woven textiles to support the vertical germination of curly cress microgreens. The final observational study involved a 5:1 scaled prototype model of a lightweight farming pavilion implementing the use of a knit coconut coir textile as the growing media. Coconut coir has been examined as a soilless substrate for microgreens, however, has not been widely examined in the context of vertical growth or media textile creation. As food demands rise, understanding the implementation of food systems in architecture of a space could promote food production, sustainability, and accessibility in necessary areas.

The series of growth trials sought to produce pertinent data about the use of coconut coir in a vertical system. The experiments, however, investigate only two commercial coconut coir mats and one coconut coir twine available online. The recorded germination success in this investigation suggests that these coconut coir products have the ability to grow microgreens in a vertical soilless media system. Though these results may not be generalized for all coconut coir products, it is important to examine the specific instances of germination success and textile creation in this design. This provides an opportunity to understand the implications these types of coconut coir products can bring to a vertical soilless media system.

As was seen in the commercial coconut coir mat growth experiments, germination success was evident on the knit media textile for the farming pavilion module application. The form active GFRP rod structure could withstand the weight of the coconut coir textiles with significant microgreen growth. The germination and construction success of the farming pavilion module investigation suggests an opportunity to probe further experimentation and calculation. A deeper analysis into the balance between stretch and stiffness of the coconut coir material and the structure could lead to other potential form active hybrids. These hybrids could focus on the integration of the media textile into the tensile structure and testing the limits of the material.

5.2 Discussion and Interpretation of Findings

The following section reveals results based upon the stated research questions:

Q1: What is the timeline and capacity of soilless growth on a commercially manufactured coconut coir mat comparable to commercial soilless farming timelines?

Q2: How can the commercial coconut coir mat be manipulated for repeated soilless media growth?

Q3: Does the application of a food-grade adhesive improve the growth and output of microgreen growth on vertical coconut coir mats?

Q4: Can a coconut coir textile support the growth of microgreen plants from germination through harvest on a lightweight structure?

Three conclusions with subsequent findings emerged from the analysis: 1) coconut coir mats have the capacity to grow microgreens vertically in a soilless system, and 2) the commercial coconut coir mats require little to no manipulation or adhesion to encourage germination, 3) and knit coconut coir textiles hold promise for farming textiles in form active architecture. According to the literature, the concept of coconut coir as a media substrate in a standard soilless system was expected. However, the resulting success of the vertical microgreen growth in the germination studies was less expected. The most unexpected outcome resulted from the food-grade adhesive decreasing and even inhibiting the growth of the microgreens while the straight seed treatment had the most success. The Konjac Gum powder, though it was used on a jersey knit material successfully in *Influence of Textile and Environmental Parameters on Plant*

Growth on Vertically Mounted Knitted Fabrics, did not improve the growth and output when applied to coconut coir.

5.2.1 Timeline and Capacity of Commercial Coconut Coir Mats

Q1: What is the timeline and capacity of soilless growth on a commercially manufactured coconut coir mat comparable to commercial soilless farming timelines?

In traditional commercial soilless farming, solid substrates like rockwool and peat are common for crop production. However, rockwool and peat have been attributed with negative environmental impacts during their production and use. Coconut coir was investigated as an alternative because of its stable physicochemical and biological properties, good water retention, aeration characteristics, and abundance. Because of coconut coir's high lignin content, it can be used multiple times without exhaustion. This study conducted multiple trials to test the capacity of the material. According to the chart in Figure 5.1, the total number of stems increased with each consecutive test. Trial one had a collective stem count for all the samples of 6,700 while trial four had 19,105. This is a 185% increase from trial 1 to trial 4.

Regarding the growth timeline, the industry standard for curled cress microgreens is between 8-12 days for harvest with artificial light and a soilless substrate. For all the growth cycles conducted in this thesis, the curled cress microgreens were ready for harvest after only 7 days. This indicates that the use of coconut coir in a controlled environment is comparable, if not faster than, commercial soilless farming timelines. This could be due to the coconut coir mat's water holding capacity, substrate depth, nutrient retention, or increased biomass creation through repeated use.

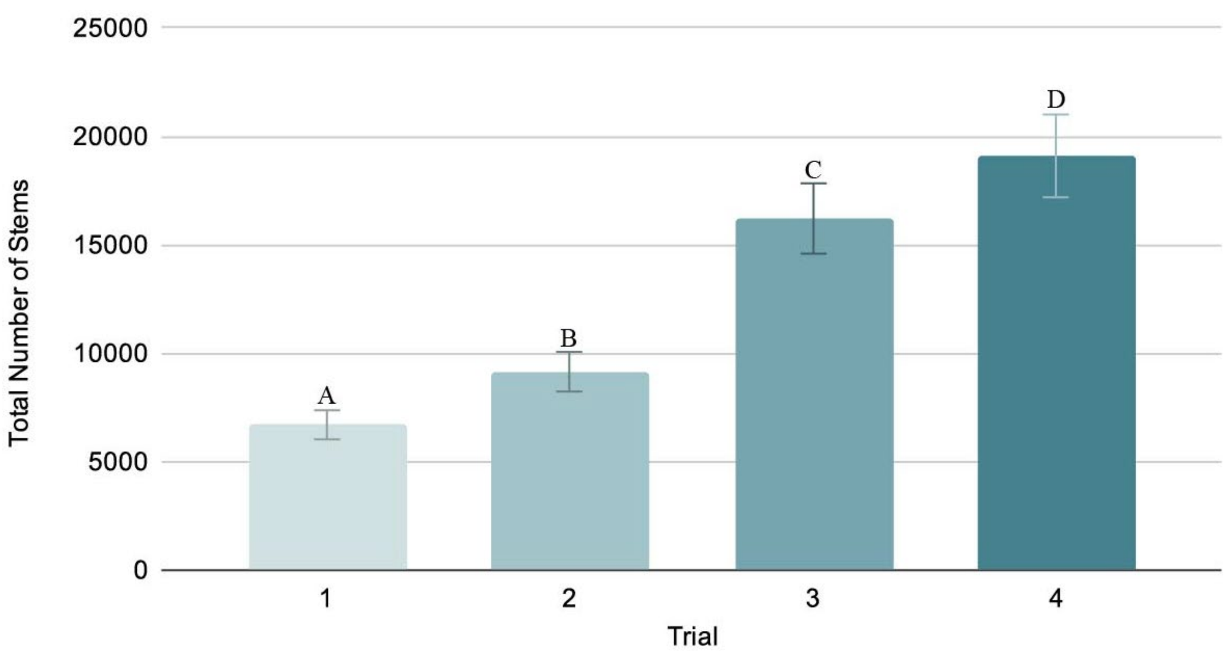


Figure 5.1: Total stem count for ***Trial 1*** *A=6700 stems (P=0.0001),* ***Trial 2*** *B=9145 stems (P=0.0022),* ***Trial 3*** *C=16,216 stems (P=0.0039), and* ***Trial 4*** *D=19,105 stems (P=0.0001)*

Not only does coconut coir maintain usability over multiple cycles but has an output increase. This could be caused by increased biomass creation with repetitive use. The increase in biomass could supply necessary nutrients to the next cycle of growth, causing increased productivity. This could also be attributed to the lowered salt content of the coconut coir mats with each consecutive growth. Coconut fiber is known to have a high salt content which could inhibit plant growth to a certain degree. It is speculated that with each growth cycle and subsequent mat soaking, the salt levels in the mat could decrease enough to encourage higher microgreen germination and plant health. With each new cycle the mat fibers were also loosened slighted due to repeated stem growth and removal. The loosening of the fibers could allow for deeper root penetration and attachment, resulting in more health microgreens. The fibers were able to loosen enough to encourage deeper roots without resulting in major fiber pull-out and degradation. This would be an advantageous element for farmers as they would be able to use the coconut coir media for multiple trials while also seeing improved production over time. These results of increased germination success through multiple trials outperforms the traditional substrates of rockwool and peat that exhaust after a single use.

5.2.2 Possible Coconut Coir Mat Manipulation

Q2: How can you manipulate the commercial coconut coir mat for repeated soilless media growth?

Based on the study *Thermal behavior assessment of a novel vertical greenery module system: first results of a long-term monitoring campaign in an outdoor test cell,* a pocketing technique could create a surface area for growth in the vertical orientation. This pocket technique suggested that the plants would have easier attachment in the vertical system without an adhesive or binding.

A germination study was developed for each of pocket treatment (POC) samples created by cutting three 4-inch (10.16 centimeter) horizontal slits halfway through the 5-inch by 5-inch (12.7 x 12.7 centimeters) mats. This created a space for the microgreen seeds to sit during germination without falling off the mat. Although this treatment resulted in microgreen growth for each trial, there were many seeds that did not germinate. Seed overlap within the pockets could have made it difficult for all seeds to reach necessary light, air, water, and mat media.

Despite the lowered germination rate, the pocket technique resulted in greater microgreen growth and stem length than the Konjac Gum (GUM) treatment. This can be seen in the chart in Figure

5.2 where the pocket treatment had an average stem length of 3.637 centimeters (1.43 inches) while the Konjac Gum treatment had 2.489 centimeters (0.98 inches). From this analysis, it can be concluded that a pocket technique is more effective for smaller numbers of microgreen seeds. The application of 2,500 seeds across a 5-inch by 5-inch (12.7 x 12.7 centimeters) mat with three pockets resulted in an abundance of ungerminated seeds.

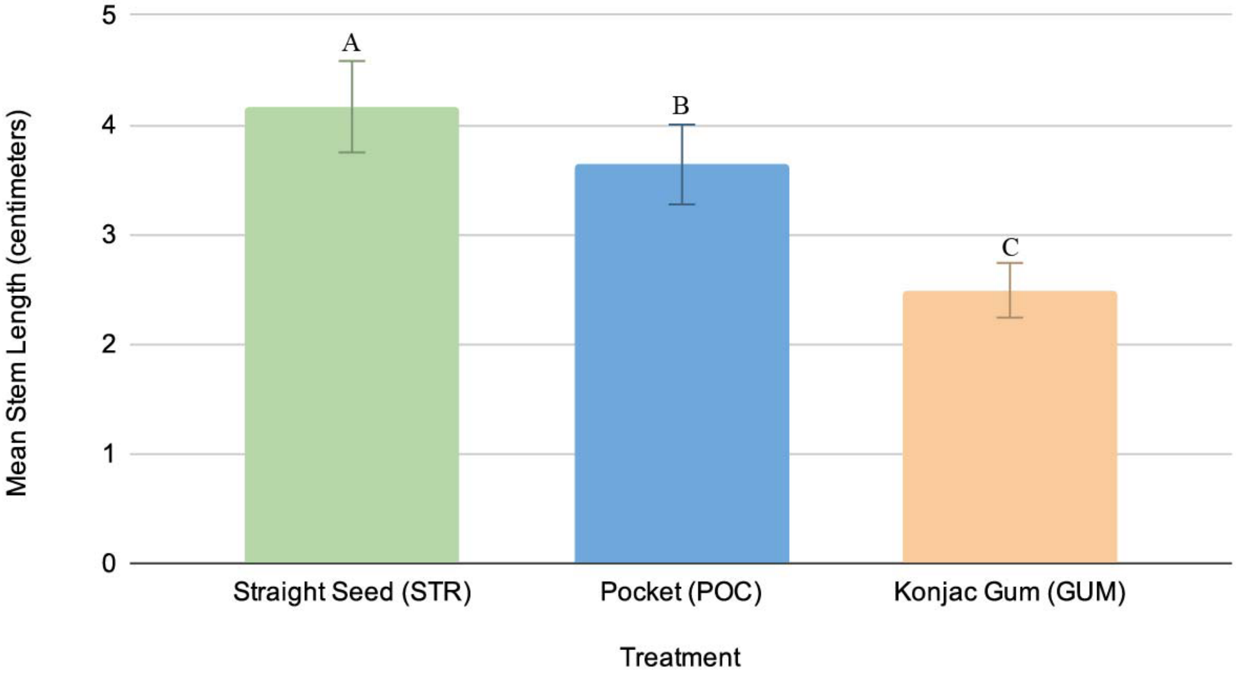


Figure 5.2: Mean stem length (centimeters) for ***straight seed (STR)*** *A=4.165 cm (P=0.0001),* ***pocket (POC)*** *B=3.637 cm (P=0.0183), and* ***Konjac Gum (GUM)*** *C=2.490 cm (P=0.0001)*

5.2.3 Food-Grade Adhesive Efficacy

Q3: Does the application of a food-grade adhesive improve the growth and output of microgreen growth on vertical coconut coir mats?

The need for a food-grade adhesive to ensure microgreen seed attachment to a vertical surface was presented in the study *Influence of textile and environmental parameters on plant growth on vertically mounted knitted fabrics but* was found to be inconsistent with the analysis of the germination study. This treatment was proven to be ineffective as the samples applied with a Konjac Gum Powder solution had considerably lower germination rates than the other two treatments of straight seed (STR) and pocket (POC). Although the Konjac Gum powder ensured that the seeds stayed on the mat through the entirety of the trial, none of the samples achieved a germination rate above 14.08% (Figure 5.3).

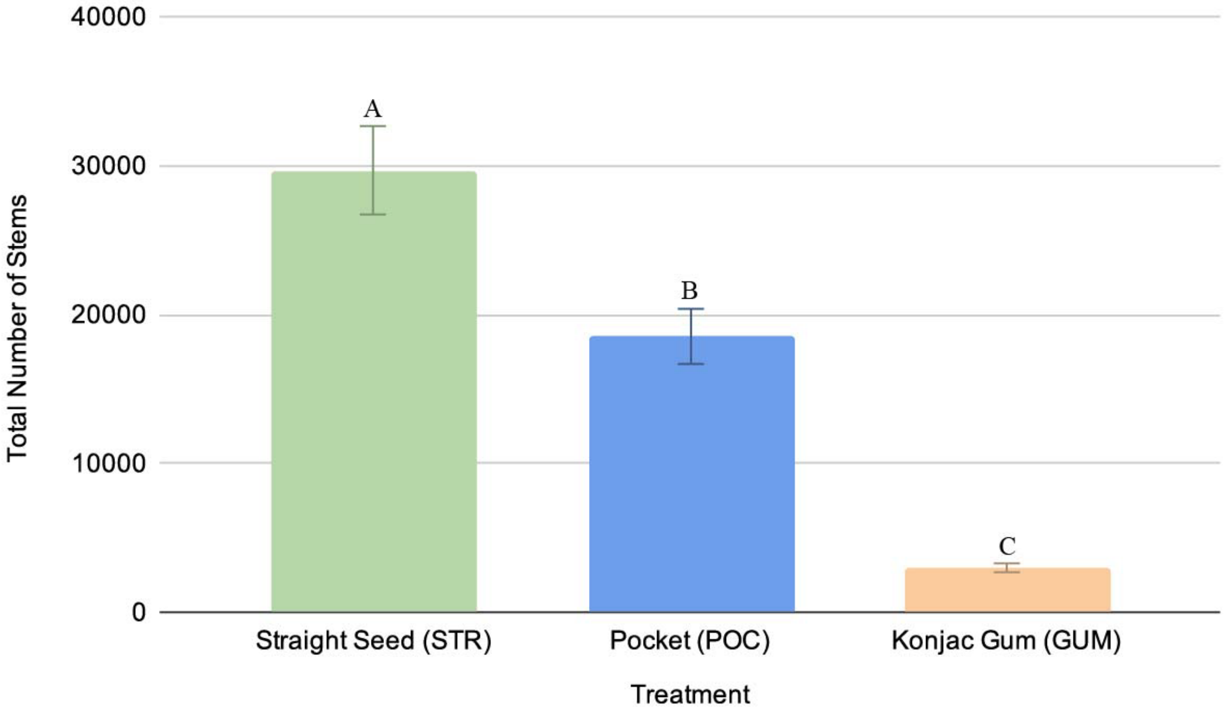


Figure 5.3: Total stem count for ***straight seed (STR)*** *A=29,676 stems (P=0.0001),* ***pocket (POC)*** *B=18,515 stems (P=0.2462), and* ***Konjac Gum (GUM)*** *C=2,975 stems (P=0.0001)*

The stems produced from the Konjac Gum treatment samples also had the shortest stem length throughout the entire study. The straight seed (STR) treatment, though unexpected, had the most success in terms of stem length, stem weight, and stem count across all the treatments. The treatment with straight seeds applied directly to the mat had the highest germination rate out of the three treatments. This proved that the addition of a secondary adhesive of Konjac Gum Powder did not improve the growth or output of microgreens on vertical coconut coir mats.

5.2.4 Coconut Coir Textile on a Lightweight Structure

Q4: Can a coconut coir textile support the growth of microgreen plants from germination through harvest on a lightweight structure?

From observations of the model after the seventh day of the growth cycle, it was noted that the microgreens had the lowest germination at the edges of the knit textiles while the highest occurred at the center. This was to be expected as the corners and edges of the coconut coir textile are the first to lose water moisture. The centers of the textiles had the highest density of microgreens which could be attributed to the water collecting at the lowest point of the textile. Because the coconut coir textiles did not function in tension as designed, they tended to hang slightly in the center. This allowed for water and seeds to collect at the middle of the textile.

The retained flexibility of the knit coconut coir textile with full microgreen growth was unexpected in this study. The commercially available coconut coir mats tested during the germination study, CocoTek and Envelor, maintained a stiffness and rigidity even through multiple uses. This could be attributed to the tight felt woven structure and the addition of the natural rubber on the CocoTek mat. To test the knit textiles, simple manipulations such as folding, twisting, and bending were conducted to visually observe the flexibility with microgreen growth. The flexibility of the media textile was not noticeably affected by the microgreens and the embedded root structure.

The farming pavilion prototype in this study was a first attempt at the creation of a textile and rod system. Even with the limited calculations and experiments, the success of the 5:1 scale model provides promising results for future research.

5.3 Significance of Study

This study revealed that coconut coir can act as a vertical soilless media for microgreens and has the potential for architectural applications. Some literature investigating vertical growth with microgreens suggested that the seeds would not adhere to the substrate without the use of a secondary material as an adhesive (Böttjer, 2019). This is not necessarily true for a coconut coir media. This finding suggests opportunities for coconut coir to support the germination of microgreens without the need of an adhesive. The mats in this case revealed to be not only sufficient for vertical growth but also increase in effectiveness through multiple uses. This greatly increases the sustainability of the coconut coir vertical growth system.

Implementing the use of coconut coir in vertical growth and textile creation has the ability to greatly impact food production and access across cities of all need levels. This, therefore, suggests a need for further study for alternative growth materials, systems, and structures. The farming pavilion investigation in this thesis provided positive results that inspire research about the possible pavilion yield. This is encouraging for future numeric data trials like what was undertaken in the germination study. This could lead to new hybrid farming pavilion modules to test yield and implementation in cities of varying environmental and social climates. This gives designers and planners a new reason to seek information on the impact of soilless media textile growth systems in cities, and the materials that are used to create them.

This study is also significant for its role in architectural applications as temporary or seasonal pop-up structures. These types of deployable systems are prevalent globally because of their seasonality, adaptability, productivity, and sustainability.

Because of the design's adaptable and sustainable features, the pavilion has the potential to be hyper-local and regional. Coconut coir is already being implemented in mattresses, floor coverings, and yarns in tropical areas where coconuts are native. These pavilion structures and coconut coir textiles could be crafted to use regional fabrication methods. This would encourage different communities and cultures to implement their own textile techniques, materials, and construction skills. A project that recognized this regionality advantage was the Portable Light Project established by Sheila Kennedy and her studio KVA MATx. The project creates new ways to deliver decentralized renewable power and light in a simple versatile textile with flexible photovoltaics and solid-state lighting. The textiles made using local materials to create energy harvesting textile bags, blankets, and clothing (Figure 5.4). The textiles can be adapted to local cultures and customized by people using traditional weaving and knitting technologies. This creates the opportunity for greater levels of cultural acceptance on the technology. The implementation of this technology allows people in different regions to create their own accessory to promote energy harvesting for their communities.

Figure 5.4: Native Huichol woman weaves a traditional K+tsuri (bag) using a strap loom (left) and woman presenting Portable Light as a traditional bag (right) (Kennedy, 2008)

This project exhibits the advantages of adaptable textile designs for hyper-local applications. These principles could be applied using coconut coir media and implementing traditional regional and local textile creation techniques.

Another significant feature of this research is the sustainable building principles. The application of the farming pavilion not only provides a simple food production structure but also a passive shading system. The coconut coir media panels offer variable sun-shading throughout the growth cycle. The bare textile allows for light to pass through the gaps in the textile but as the plants grow, the shading capabilities increase. The necessary watering and plant growth also provides passive cooling through evapotranspiration. As the plants release water from their leaves via transpiration, the surrounding air is cooled as water goes from liquid to vapor. This creates a shaded and cool deployable structure.

5.4 Recommendations for Further Research

This study examined only one type of microgreen because of its short germination time, light weight, and known ability to grow in a soilless system. It is important for more applications of a variety of plants to be examined to test the breadth for which coconut coir can be used. Studying the elements of root structure, dead weight, media depth, water retention, and germination rate for larger plants could expand the use of coconut coir in vertical soilless media systems.

Coconut coir as a soilless media textile for architectural applications could be investigated further for design implication and proof of concept by modeling the farming pavilion at full-scale. Coconut coir knit textiles require better understanding of its tensile capacity. Testing the mechanical properties of a coconut coir textile can lead to investigations between flexibility and rigidity of a form active architecture. The dichotomy between stretch and stiffness in relation to the textile and structure could lead to other hybrid structural systems. Further development of the textile integration into the structure could lead to a dynamic spatial network for growth systems. This would allow for a deeper understanding of the effects of dead load, environmental conditions, and reusability for the lightweight structure.

The investigation of the farming pavilion was completed in a short time frame due to scheduling limitations and scope of study. Multiple iterations of this design and prototyping process provide a more comprehensive understanding of how the entire system (textile and GFRP rods) works in tension, how environmental factors such as changing seasons may influence the structure, and how different textile patterns and designs affect growth. The prototype was also tested in a controlled environment and would need to be studied in an outdoor setting.

5.5 Limitations

Due to semester deadlines, constraints of resources and limited knowledge of structural calculations, an observational study was chosen. Materials were limited to what could be ordered online, and the physical model was scaled based on the size of the available lab space and tent. A smaller scale model provided preliminary insight, while allowing the analysis to remain manageable and feasible within the available time and space. With a longer timeline or larger testing space, a more comprehensive collection of results could be conducted.

Due to limited time and structural knowledge, the architectural application was limited to its observational findings. Proper calculations, prototypes, and growth trials were not able to be conducted in the allotted time frame to provide numeric data and analysis of the system. Although the digital representation and observational prototype were promising for future research, definitive experiments would need to be conducted to have proof of concept.

The sustainability of the project was a motivating factor but may not have reached its full potential. Although coconut coir is a waste-product, the areas that produce coconut coir materials like mats and yarns are typically subtropical coastal regions such as India, Philippines, Sri Lanka, Thailand, and Indonesia. To be implemented in this study, and future investigations in the United States, the materials would need to be imported into the country. This would reasonably lower the sustainability attributes associated with the material and the overall system. Because of this, these deployable farming pavilion may have the most sustainable impact in regions with high coconut production and consumption. This would also address the limitation of geography and seasonality. These tropical regions would get the most use out of the farming pavilions because of their temperate climates for most of the year. This would allow for continuous food production because of favorable temperatures, precipitation, and humidity. The growing pavilion would have a difficult time performing in areas with drastic seasonal changes. In continental climates, the pavilion would have to be deployable in the warmer months and either left bare or disassembled during the off-season. This could lead to lower implementations of the farming pavilion in regions that experience seasons unfit for year-round food production.

5.6 Conclusions

When coconut coir is applied in a vertical soilless media system, it can support culinary growth. This statement concludes that coconut coir can be implemented as a soilless media textile for lightweight deployable structures. The coconut coir provided water retention, soilless nutrients, and root adherence without requiring a secondary adhesive for germination. The resulting stem length, stem weight, stem count, and total weight statistics provided evidence of germination success. These results reveal that coconut coir textiles can inspire a new approach to vertical growth systems. Whether it is a small home growing wall or a community farming pavilion, coconut coir textiles show potential in the development of architectural growth systems. These findings suggest a need to investigate coconut coir for its ability to enhance food production, sustainable materials, and built spaces.

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APPENDICES

Appendix A- Curly Cress Microgreens

A preliminary study was conducted to select one type of microgreen seeds to be used in this thesis. A chart was created to organize attributes for all the microgreen species considered to aid in the selection process. Features included: light restriction (blackout) period, online availability, no required pre-soaking, color, seeding rate (ounces per 200 inch^2), germination rate, blackout time, and growth. Curly cress seeds were chosen because they have a seeding rate of one ounce per 200 inch^2, a germination rate of one to two days, no blackout time, and a harvest time between eight and twelve days. This was ideal due to testing time constraints.

Microgreen Selection Chart

			Attributes				
	Species	Latin Name	Color	Seeding Rate (10"x20" tray) (Ounces)	Germination Rate (Days)	Blackout Time (Days)	Harvest Time (Days)
1	Alfalfa	*Medicago sativa*	Green	1	1-2	3-4	8-11
2	Amaranthus	*Amaranthus viridis*	Pink/Red	0.6	2-3	4-5	8-10
3	Arugula	*Eruca vesicaria ssp. sativa*	Green/Purple	1	2-3	4-5	7-10
4	Broccoli	*Brassica oleracea var. italica*	Green/Pink	1	1-2	4	7-10
5	Brussel Sprout	*Brassica oleracea var. gemmifera*	Green/Pink	1.2	2-3	3-4	7-10
6	Cauliflower	*Brassica oleracea var. botrytis*	Green/Purple	1.5	2-3	4-6	8-12
7	Celosia	*Celosia argentea*	Green/Red	1	2-3	4-5	8-12
8	Chia	*Salvia hispanica*	Green/White	1	1-2	4-5	10-12
9	Clover	*Trifolium*	Green	1	1-2	3-5	7-12
10	Collard	*Brassica oleracea var. viridis*	Green/Pink/White	1.2	1-2	4-5	7-10
11	Cress	*Lepidium sativum*	Green/White	1	1-2	0	8-12
12	Endive	*Cichorium endivia*	Green	1	2-3	3-4	7-12
13	Flax	*Linum usitatissimum*	Green/Pink	1	2-3	4	8-12
14	Kale	*Brassica oleracea var. sabellica*	Green/Pink	1	2-3	4	6-10
15	Kohlrabi	*Brassica oleracea Gongylodes Group*	Green/Purple	1	1-3	3-4	7-10
16	Leek	*Allium porrum*	Green	1	3-4	4	10-12
17	Mache	*Valerianella locusta*	Green	1	2-3	3-4	8-12
18	Marigold	*Tagetes*	Green	2	2-4	3-4	8-14
19	Mizuna	*Brassica rapa var*	Green/Purple/Pink	1	1-2	3-4	8-12
20	Mustard	*Brassica*	Green/Pink	1	3	3-4	7-10
21	Radish	*Raphanus sativus*	Green/Pink	1.5	1-2	3-4	8-10
22	Rutabaga	*Brassica napobrassica*	Yellow/Green/Pink	1	2-3	3-4	8-12
23	Sesame	*Sesamum indicum*	Green/White	1	2-3	3-4	7-10
24	Sorrel	*Rumex acetosa*	Green	1	1-2	3-4	10-12
25	Tatsoi	*Brassica rapa subsp. narinosa*	Green/Yellow	1	1-2	3-4	8-12
26	Turnip	*Brassica rapa subsp. rapa*	Green/White/Pink	1	2-3	3-4	8-12
27	Wheatgrass	*Elymus trachycaulus*	Green	1-2	2-3	0	7-12

Appendix B- Germination Study

The following charts show the raw data collected for all four of the germination trials for the Chapter 3: Germination Study. The tables are separated by trial and mat type and include the data collected for the tent environment. For each of the trials, the data variables that were collected include: number of seeds, total weight, stem count, stem weight, mat dry weight, mat wet weight, stem lengths, average stem length, relative tent humidity, tent temperature during the day, tent temperature during the night, and germination rate. This data was used in the data analysis for the thesis.

Growth Cycle 1

COCONOT COIR MAT DATA

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
DATA SETS	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*
Number of Seeds	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Total Weight (ounces)	1.3	1.9	1	1.1	1	1.3	1.3	1.9	1.2	1.2	1.2	1.3	0.9	1	0.9	2.6	1.2	2.3
Stems	500	587	105	303	114	200	115	247	103	1100	874	1100	360	275	123	88	154	352
Stem Weight (ounces)	0.2	0.9	0.3	0.2	0.2	0.3	0.2	0.3	0.1	0.4	0.3	0.6	0.3	0.2	0.1	1.1	0.2	0.6
Mat Dry Weight (ounces)	0.8	0.6	0.6	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.9	0.7	0.9	0.8	0.8	0.9	0.8	0.7
Mat Saturated Weight (ounces)	1.1	1	0.7	0.9	0.8	1	1.1	1.6	1.1	0.8	0.9	0.7	0.6	0.8	0.8	1.5	1	1.7
Average Length (centimeters)	4.048	3.924137931	3.66	3.57	2.881818182	3.305	2.245454545	2.85	2.24	4.261818182	3.654545455	4.2	4.605555556	3.344444444	2.783333333	2.3875	2.746666667	2.36
Relative Humidity (%)	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56	56
Temperature Day (Farenheit)	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9	82.9
Temperature Night (Farenheit)	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6	67.6
Germination rate (%)	**20.00%**	**23.48%**	**4.20%**	**12.12%**	**4.56%**	**8.00%**	**4.60%**	**9.88%**	**4.12%**	**44.00%**	**34.96%**	**44.00%**	**14.40%**	**11.00%**	**4.92%**	**3.52%**	**6.16%**	**14.08%**

TENT CONDITIONS

TENT HUMIDITY

	Day						
Time of Day	**1**	**2**	**3**	**4**	**5**	**6**	**Average**
Day	57	60	71	56	52	62	**59.66666667**
Night	85	99	85	82	83	80	**85.66666667**

TENT TEMPERATURES

	Day						
Time of Day	**1**	**2**	**3**	**4**	**5**	**6**	**Average**
Day	81.9	81.1	82.4	82	81.3	81.9	**81.76666667**
Night	70	70.2	57.6	68.7	68.9	68.7	**67.35**

STEM LENGTHS

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
	Sample #1	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*
Stem Lengths (centimeters)																		
1	5.1	1.4	3.8	4.1	3.8	4.1	3.7	2.3	2.3	2.9	5.7	2.5	3.4	2.8	3.1	2.3	2.3	3.2
2	5.4	5.8	3.4	5.7	3.4	3.5	1.3	2.7	3	4.8	2.7	5.4	3.3	5	3.7	3.2	2.2	2.2
3	3.7	4.2	3.5	3.8	1.5	3	1.7	3.9	2.6	5.8	4.4	5	5	4.8	3.1	1.6	3.9	1.7
4	7.5	4.2	2	3.5	2.6	2.4	1.5	2.2	2	5.8	3.7	6.1	3.5	2.6	3.7	2.5	3.4	1.8
5	2	3.6	3.5	2.5	2.5	3	3.2	2.5	1.7	4.3	4.3	4.3	2.7	2.3	2.9	1.7	2.1	3
6	2	4	3.1	3	1.1	5.7	2.3	2.8	1.2	2.7	2.7	2.5	3	2.2	1	1.6	3.1	2.7
7	4.5	3.9	4.5	2.4	3.4	3.5	1.6	2.6	2	6.8	3.5	3.3	3.7	4.7	2.2	3	2.2	2.3
8	6.5	4.3	4.1	2.8	2.6	5	2.5	3	3	4.4	2	3.6	4	3	3.1	3.2	2.8	2.3
9	6.5	2.4	3.7	4.2	3.9	4	3	3.6	2.6	6	3.5	3.5	3.8	3.4	3.4		2.6	3.9
10	4	2.2	5	4.7	2.8	3.5	1.6	3.4	2	7	2.5	5.2	3.2	2.9	2.7		2	2
11	6.5	5.6		3.6	4.1	3	2.3	2.3		2.2	5.2	2.5	4.5	3	2.3		3	3.7
12	7.2	3.5		2.4		2.3		2.5		4.5	4.9	4.8	5.2	3.2	2.2		3.2	2.3
13	2	5		3.8		4		3.4		2.5	5.7	3.6	4.2	4.3			3.5	1.8
14	3.6	3.5		2.5		3.2		3.5		5.5	5.5	3.4	3.3	2.5			2.4	1.6
15	3.2	1.9		2.7		2.8		1.5		4.1	7.7	3.9	2.9	2.7			2.5	1.8
16	4	1.5		2.6		2.7		2.6		4	5.5	3.6	3.5	4.5				2.5
17	2.9	4		4.5		3.3		3.9		5	2.4	1.3	3.9	3.7				2.6
18	3.5	4.9		3.1		1.1		3.8		3.5	3.5	2.5	5.1	2.7				1.7
19	4.7	4.6		5.2		2.6		2.5		4.9	5.2	3.5	3.4	2.5				2.3
20	4.2	5.5		4.3		3.4		2.6		4	5.5	5	5.8	2.7				3
21	2.8	4.5		2.7				2.2		5.4	1.2	3.3	4	4.6				2.2
22	3.5	3		3.1				2.1		6.4	5.2	4.5	3.5	2				1.5
23	2.3	5		4.6				3.1		1.4	3.3	3.4	6.3	5.2				2.4
24	2.4	5.5		5.7				3.4		3.4	5.6	3.3	4	4.3				1.6
25	5	2.5		2.9						6	3.2	5.2	5.9	4.2				1.5
26	4.5	4		3.6						4.7	1.5	3.6	3.2	2				3
27	5.7	1.8		3.2						8.8	7.5	3	5.5	2.5				1.7
28	2	2.2		4						6.8	2.5	3.4	3					2.5
29	5.3	5.5		3.9						4	3.5	3.7	2.5					1.3
30	6	4		2						1.3	3.3	3.3	3.6					1.6
31	3.3	3.2								5.7	1.2	4.5	3.7					3.7
32	7	3.4								5.2	5.5	5.2	2.7					2.3
33	5.4	2.8								3.5	5.4	6.5	31					3

34	3.7	2.3								3.3	5.8	2.5	2.2					3.2
35	3.1	3.1								6.2	5.2	3.7	3.3					2.7
36	2	4.6								3.5	4.3	4.5	4					
37	2	5								2.3	5	3.5						
38	4.5	2.2								3.4	4.8	6.5						
39	6	3.6								5.3	3	4.4						
40	4.1	6.5								5.5	3.5	4.3						
41	2.9	1.6								4.4	3.8	4.5						
42	1.5	6.8								3.8	3.7	5.5						
43	3.7	6.6								6.4	4.1	5.1						
44	1.8	4								5.5	3.3	3.6						
45	4.7	2								3.3	5	3.4						
46	3.1	4.7								2.7	2.5	6.1						
47	3.3	5.9								4	3.5	3.5						
48	6.8	4.3								3.2	4.3	5.6						
49	3	5.1								3.4	3.6	4						
50	2	4.5								4.2	1	4.2						
51		5.4								3.5	3.7	4.5						
52		3.7								3.1	2.6	3.9						
53		1.6								3.9	2.5	5.5						
54		3.4								4.6	1.5	3.2						
55		4.7								2.6	4.2	3.7						
56		2								5	3.4	3.9						
57		4								2.5	2.7	5.1						
58		6.6								4	3.5	3						
59										4.9	6.1	3.6						
60										2.8	4.7	5						
61										3	2.2	3.9						
62										3	5.1	3.4						
63										3.5	3.2	3.4						
64										5	3	2.5						
65										3.5	4.4	4.5						
66										7	5	3.8						
67										1.4	7.3	4.3						
68										7.9	1	4.5						
69										4.3	3.6	3.6						
70										5.5	5	4.2						
71										3.7	5.6	5.5						
72										2	3.2	3.6						
73										4.2	1.5	5						
74										3	1.7	1.3						
75										4.7	4.2	4						
76										5	3.2	7.4						
77										3.4	3.3	3.5						
78										2	3	2.3						
79										7.2	5.6	2.3						
80										3.8	2.3	3.5						
81										5.2	4.5	6.3						
82										3.2	3.7	3.7						
83										5.5	5.7	4.2						
84										2.5	2.2	4.2						
85										3	6.3	3.2						
86										4.5	1.5	4.5						
87										4.5	3	3						
88										4.6		4.8						
89										2.7		5.1						
90										3.8		5						
91										2.5		6						
92										5		2.3						
93										4.2		6.5						
94										6.9		4.2						
95										5		3.6						
96										5.4		2.5						
97										3.7		5.2						
98										6.8		3.5						
99										5		4.7						
100										4.1		5.6						
101										2.6		7						
102										4.5		5.5						
103										2.7		6.5						

104										3.7		4.8						
105										4.6		6.4						
106										5.2		4						
107										3.5		6.1						
108										3.3		4.2						
109										3.2		3.5						
110										3.7		4.7						
Average Lenth (centimeters)	**4.048**	**3.924137931**	**3.66**	**3.57**	**2.881818182**	**3.305**	**2.245454545**	**2.85**	**2.24**	**4.261818182**	**3.654545455**	**4.2**	**4.605555556**	**3.344444444**	**2.783333333**	**2.3875**	**2.746666667**	**2.36**

Growth Cycle 2

COCONOT COIR MAT DATA

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
DATA SETS	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*
Number of Seeds	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Total Weight (ounces)	2.4	2.3	2.9	2.4	2.7	2.2	2.6	2.8	2.9	3.4	3.7	2.6	2.6	3.5	2.8	2.9	2.3	3.3
Stems	1100	1167	1328	343	492	300	50	77	47	1096	959	460	200	893	509	41	83	0
Stem Weight (ounces)	0.6	0.9	1.2	0.3	0.5	0.5	0	0	0	1.1	1.2	0.8	0.3	1	0.7	0	0	0
Mat Dry Weight (ounces)	0.8	0.6	0.6	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.9	0.7	0.9	0.8	0.8	0.9	0.8	0.7
Mat Weight (ounces)	1.8	1.4	1.7	2.1	2.2	1.7	2.6	2.8	2.9	2.3	2.5	1.8	2.3	2.5	2.1	2.9	2.3	3.3
Average Length (centimeters)	3.99	3.526724138	4.203030303	3.064705882	3.467346939	3.053333333	2.08	2.828571429	2.025	3.814678899	3.944210526	3.569565217	3.33	3.147191011	2.894	4	2	0
Relative Humidity (%)	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5	80.5
Temperature Day (Farenheit)	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93	81.93
Temperature Night (Farenheit)	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5
Germination Rate (%)	**44.00%**	**46.68%**	**53.12%**	**13.72%**	**19.68%**	**12.00%**	**2.00%**	**3.08%**	**1.88%**	**43.84%**	**38.36%**	**18.40%**	**8.00%**	**35.72%**	**20.36%**	**1.64%**	**3.32%**	**0.00%**

TENT CONDITIONS

TENT HUMIDITY

	Day						
Time of Day	**1**	**2**	**3**	**4**	**5**	**6**	**Average**
Day	56	52	62	62	62	64	**59.66666667**
Night	85	82	80	79	77	80	**80.5**

TENT TEMPERATURES

	Day						
Time of Day	**1**	**2**	**3**	**4**	**5**	**6**	**Average**
Day	82	81.3	81.9	82.2	82.2	82	**81.93333333**
Night	67.7	67.6	67.3	67.4	67.4	67.6	**67.5**

STEM LENGTHS

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
	Sample #1	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*
Stem Lengths (centimeters)																		
1	3.3	2.4	5	3.3	5.7	4.3	2.5	2.3	2.3	3.7	4	3.2	3.5	2.2	5.9	10.4	2.4	
2	2.5	2	4.1	3	4.1	3.5	1.6	3.9	1.8	5.5	6.4	4.5	3.9	4.7	2	2.8	2.3	
3	3	4.3	2.6	2.8	3.9	5.7	1.5	2.7	2	4	4.8	4	5	3	2.5	1.3	3	
4	3.5	3.9	4.5	3.5	3	4.1	1.6	2.2	2	5.7	3.5	4	3.7	3.4	5	1.5	1.5	
5	3.6	4	2.7	2.8	3	3.9	3.2	2.4		2.7	4.3	2	3	2.3	2		1.6	
6	2	4	2.9	3.4	2.4	2.3		3.1		4.4	2.5	3.6	2.9	4.2	3		2.3	
7	4.8	3.6	4.3	3.9	2.5	3.2		3.2		3.7	4.4	3.1	2.6	4.3	3.4		1.5	
8	3.2	4.2	2.5	2.6	3	3				4.3	2.5	2.6	2	5.2	2.2		1.4	
9	4.6	4.2	3	3.4	3	1.7				2.7	5.5	6	3.1	6.5	3			
10	2.7	2.2	3.4	1.1	4.2	1.4				3.5	7	3.5	3.1	3.7	3.7			
11	7	4.8	3	3.3	2.8	3.2				2	4.7	2.5	4.4	3.2	2.9			
12	2.5	1.6	3.1	2	3.5	2.5				3.5	3.5	4	4.8	3.7	3.1			
13	3.2	3.6	4.6	2.5	4.3	4				3.3	5.2	2.4	2	2	1.5			
14	4.6	5	4.7	1.5	2.9	2.4				3.4	2.5	5.5	1.5	4.6	2.9			
15	4.5	3.5	5.5	3.8	3.5	3.4				7	4.6	3.3	4.1	2.7	1			
16	5.7	5.6	3	2.9	4.1	3.4				6.3	7	5.5	3	2.5	2.9			
17	2.5	2.2	3.8	3.5	3.5	3.9				4.2	3.3	2.7	3.2	2.9	3.1			
18	3.6	2.4	3.6	4.1	4.3	2.6				4.9	3.5	5.5	2.3	5.2	2.7			
19	1	5.5	3	4.2	3	3.4				2.5	4	1.9	6	2.9	3.7			
20	5.5	2.2	5.1	3.5	4.8	1.1				1.5	2.6	6.4	2.5	4.5	3.5			
21	2.8	3	3.9	3.6	2.3	2				5.1	2.5	6.1		2.2	3.1			
22	5.8	3.2	3.7	3	3.2	1				2.4	4.4	3.1		4.1	3.3			
23	6	2.5	4.6	2.5	4	4.2				4.4	2.5	3.4		2.6	2.5			
24	2.5	3.4	7.5	2.4	2.4	4.2				1.5	4.3	2.1		2.6	2.3			
25	4	6	6.1	3.4	2.4	3.8				2.9	3.5	3.5		4	2.7			
26	2.6	2	5	3	4	3.4				3.6	4.6	4.8		3.2	2.2			
27	2.8	2.4	6.3	4.3	3.2	1.5				1	3.6	3.4		3.9	3.1			
28	4.2	3.7	4.5	2.5	2.3	2.6				3.7	5.4	2.9		4.3	4.5			
29	4.7	3.8	6.3	3	4.8	2.6				2.6	3.9	2.2		3	2.6			
30	6.5	5	3.9	4.2	3	3.3				2.5	2.6	2.5		5.2	3			
31	3	2.6	2.2	2.8	4.3					1.5	1.3	4.1		6.1	2.2			
32	3.8	2.4	3.8	3	3.5					4.2	4	3		2.7	5			
33	5.2	1.8	2	2.4	4					3.4	3.5	1.5		6	2.3			

34	6.6	1.9	2	3	4					2.7	2.5	4		6.2	3.7			
35	3.1	1.1	1.3		3					2	3.3	2.7		3.7	2.8			
36	7.5	4	1.1		3.5					5.6	4.5	4		5.2	1.9			
37	2.9	3.6	6		3.8					4.4	4.5	3.2		2.7	3			
38	6.2	3.2	6.1		5.7					7.3	3.4	3.5		2.5	3.1			
39	1.8	4.2	5.1		4.1					3	6.5	2.8		6.5	2.2			
40	4.5	4.3	5		2.8					5.5	3.3	5.6		3.9	1.6			
41	3.5	2	5		2.5					1.7	4.2	3.1		2.2	2.1			
42	3.6	5.9	5.1		2.5					2	5.2	2.8		2.5	1			
43	3.7	3	4		1.4					3.5	7	3.2		3.3	2.5			
44	3.6	4.5	6		5.8					4.2	3.6	3.1		1.9	1.7			
45	2	5.9	5.7		3					3.4	5.5	4.2		2.8	2.3			
46	4.6	4.3	3.9		3.9					6.1	4.5	3.2		2.2	4			
47	6.4	7	4.9		3.5					5.2	5.2			3.2	4.7			
48	2.4	4.5	5		3					3.7	4			2.8	2.5			
49	3.2	5.4	5.5		2.5					4.5	4.8			3.5	3.7			
50	6.5	3.7	2.7							2.3	3.9			2.4	3.1			
51	5.8	1.6	3.3							5.6	2.6			2.5				
52	3	2.2	5.5							3.3	2.3			1.6				
53	2.5	2.3	3.1							7.5	5.5			3.1				
54	4	3.3	3.1							3.7	2.6			3.4				
55	1.8	2	3.4							4.5	2.5			1.7				
56	4.7	7	5.3							2.3	4.5			2.7				
57	2.7	4.8	3.5							5.6	4			1.5				
58	4.5	3	2							3.5	3			2.4				
59	4.1	1.5	3							2.5	4.3			1.9				
60	5.1	3	3.5							3.5	4.7			1.5				
61	5	5.5	3.1							5	3			2.3				
62	4.5	2.2	4.5							3	3.9			1.7				
63	3.2	2.7	5							5	3.4			2.2				
64	2.9	4.2	2.6							2.5	2.5			2.7				
65	1.4	3.2	7.9							4.5	3.7			3.2				
66	6.5	2.7	2.9							7.5	5.2			2.5				
67	2.5	6.5	3.8							1.7	3.3			2.7				
68	7.4	2.5	4.8							5.9	3.6			4.2				
69	3.5	2.1	5							5.7	4.5			2.4				
70	5.3	5.8	5.8							5.5	4.3			3				
71	3.5	2	1.4							3.5	6.3			1.8				
72	3.5	4.5	5.8							5.5	2.5			2.9				
73	6	1.8	3.8							3	5.5			4.3				
74	5.5	6	5.8							2	2.3			2.3				
75	2.7	2.1	4.3							3.2	5.4			4.2				
76	4.8	2.7	2.7							1.2	5.1			2				
77	2.2	4.5	2.8							4.2	3			3				
78	3.8	2	1.4							6.3	3			4.2				
79	5.2	3.5	7							1.5	5			1				
80	1.8	4	3.5							4	5.5			1.2				
81	4.1	4.3	5							4	1.3			1.6				
82	3.1	2	3.5							4.2	4			2.7				
83	5.5	5	3							2.9	4.2			3.1				
84	3.1	1.1	3							5	3.5			3				
85	6.6	3	2.8							7.3	2.3			1.9				
86	3.2	6.8	4.9							1	2.3			1.8				
87	4.7	4.1	4							3.6	3.5			2.8				
88	1.8	3.1	5							5	6.3			3.7				
89	3.6	6.1	2.5							5.6	3.7			2.3				
90	4.1	3	5							3.2	2.5							
91	3.5	5.5	6							1.5	2.6							
92	2.4	5.5	3.4							5.7	3.4							
93	4.5	3.4	4.2							3.5	2.5							
94	5.7	2.4	4							2	3.6							
95	2	4.8	5.5							3.5	4.2							
96	5.3	4.7	8							2.7								
97	3.3	2.2	6.7							4.3								
98	6	4.5	3.4							3.7								
99	1.6	2.9	2							4.4								
100	5.9	4.3	5.1							2.7								
101	2.7	2	4							5.7								
102	4.5	5	6							5.8								
103	3.1	1.8	3.7							2.3								

104	3.7	3.4	3							1.3								
105	4.8	3.8	4							1.6								
106	4	3.7	3.2							1.2								
107	2.9	5	3.5							3.5								
108	3.5	2.6	3.7							5.8								
109	5.2	2.4	4.1							5.4								
110	5.8	1.8	2.5															
111		1.9	3.8															
112		1.1	5.2															
113		3.2	5															
114		5	4.2															
115		2.9	6.9															
116		2.1	5															
117			4.6															
118			4.7															
119			5															
120			4.1															
121			5.3															
122			3.7															
123			4															
124			5															
125			3.5															
126			5.1															
127			3.9															
128			4.6															
129			2.6															
130			4.8															
131			4.7															
132			6.2															
Average Length (centimeters)	**3.99**	**3.526724138**	**4.203030303**	**3.064705882**	**3.467346939**	**3.053333333**	**2.08**	**2.828571429**	**2.025**	**3.814678899**	**3.944210526**	**3.569565217**	**3.33**	**3.147191011**	**2.894**	**4**	**2**	**0**

Growth Cycle 3

COCONUT COIR MAT DATA

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
DATA SETS	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*
Number of Seeds	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Total Weight (ounces)	2.4	2.0	2.8	3.1	2.9	3.0	1.4	1.4	1.5	2.4	3.1	2.0	3.9	3.1	3.3	3.2	1.5	2.0
Stems	1315	1315	1690	800	664	1168	188	73	100	1634	1804	1167	1389	862	1435	163	53	96
Stem Weight (ounces)	0.9	0.6	1.2	0.7	0.8	1.1	0.1	0.1	0.1	0.9	1.1	0.8	1.1	0.9	0.8	0.1	0.1	0.1
Mat Dry Weight (ounces)	0.8	0.6	0.6	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.9	0.7	0.9	0.8	0.8	0.9	0.8	0.7
Mat Weight (ounces)	1.5	1.4	1.6	2.4	2.1	1.9	1.3	1.3	1.4	1.5	2.0	1.2	2.8	2.2	2.5	3.1	1.4	1.9
Average Length (centimeters)	4.261068702	3.628461538	4.385798817	3.34125	3.318181818	3.109482759	2.266666667	2.6	2.2	4.119631902	4.17877095	3.628448276	3.871014493	3.534883721	2.946853147	3.19375	1.96	2.133333333
Relative Humidity (%)	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6
Temperature Day (Farenheit)	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4	81.4
Temperature Night (Farenheit)	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82	68.82
Germination Rate (%)	**52.60%**	**52.60%**	**67.60%**	**32.00%**	**26.56%**	**46.72%**	**7.52%**	**2.92%**	**4.00%**	**65.36%**	**72.16%**	**46.68%**	**55.56%**	**34.48%**	**57.40%**	**6.52%**	**2.12%**	**3.84%**

TENT CONDITIONS

TENT HUMIDITY

	Day					
Time of Day	**1**	**2**	**3**	**4**	**5**	**Average**
Day	60	60	56	53	51	**56**
Night	85	82	80	79	77	**80.6**

TENT TEMPERATURES

	Day					
Time of Day	**1**	**2**	**3**	**4**	**5**	**Average**
Day	81.5	81.3	81	81.9	81.3	**81.4**
Night	68.7	68.9	68.7	68.9	68.9	**68.82**

STEM LENGTHS

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
	Sample #1	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*	*Sample #1*	*Sample #2*	*Sample #3*
Stem Lengths (centimeters)																		
1	4.1	4.2	7.9	2.9	3.7	2.5	3.2	2.2	1.7	3.5	4.8	2.1	2.2	2.2	3.5	3.5	2.3	1.4
2	5.1	3.2	6.8	3.5	1	3.5	3.0	2.7	2.3	3.0	4.5	3.1	4.0	2.9	2.2	1.4	1.5	2.0
3	7.0	3.6	4.1	4.1	4.2	6	2.3	3.9	2.0	4.8	4.7	4.5	3.0	1.9	1.6	4.1	1.5	4.0
4	4.5	4.0	1.4	4.2	4.2	3.8	3.7	2.3	3.0	5.0	4.1	2.2	7.3	3.3	2.2	2.8	3.0	1.5
5	3.2	1.1	3.1	3.5	3.8	5.7	1.6	2.3	1.8	4.3	4.3	4.0	4.9	2.5	5.2	1.5	1.5	1.5
6	2.9	1.9	3.0	3.6	3.4	4.1	1.3	3	2.6	5.2	5.5	5.0	2.3	2.2	4.3	2.4		3.7
7	1.4	1.8	3.5	3	1.5	3	2.5	1.8	2.0	2.5	6.8	3.5	5	3.9	2.4	15.0		2.5
8	6.5	2.4	3.5	2.5	2.6	3.7	1.7		2.0	5.8	3.7	4.0	4.3	6.5	3.2	4.0		1.0
9	2.5	2.6	4.8	2.4	2.5	2.9	3.0		2	5.4	3.8	4.2	2.6	2.5	2.9	2.5		1.6
10	2.5	5.0	3.1	3.4	3.5	3.7	1.5		2.6	5.5	5.2	2.9	4.1	2.7	3.7	1.3		
11	7.4	3.8	6.4	3	4.3	2.7	1.6			1.2	7.0	6.3	3.5	5.2	3	2.1		
12	3.5	3.7	3.8	4.1	4.1	3.1	1.5			3.3	4.6	4.1	3.5	2.2	4.8	2.5		
13	3.1	2.4	2.5	5.7	3.9	2.9	1.7			3.5	3.2	3.5	6.7	4.1	3.4	2.8		
14	5.4	4.2	2.0	3.8	3	2.1	3			2.5	4.5	3.2	3.3	2.6	4.2	1.5		
15	9.0	2.7	2.9	3.5	1	2.9	2.3			2.0	3.0	4.0	1.5	2.6	4.7	2.4		
16	2.7	2.2	4.3	3	5.7	3.2	1.6			5.6	8.8	2.0	2.5	4	1.6	1.3		
17	2.4	5.5	2.5	5	2.6	1.7	2.3			4.4	5.1	2.2	4.6	3.2	2.3			
18	7.5	3.0	3.0	4	3.2	4.7	3			7.3	5.0	4.0	5.9	3.9	3.1			
19	5.8	1.5	3.4	4	4.2	2.8				3.0	6.0	5.0	5.9	4.3	3.1			
20	7.2	3.0	3.0	3.5	3.8	3.1				5.5	4.0	3.0	3.5	3	3.7			
21	4.5	4.8	3.1	4.3	5.8	2.4				1.7	6.5	5.1	2.3	5.2	2.5			
22	3.7	7.0	4.6	3	5.1	2.2				2.0	4.2	4.3	4	6.1	4			
23	3.2	2.0	4.7	4.8	2.8	2.5				3.5	3.6	4.6	6.3	2.7	4.7			
24	5.0	3.3	5.5	2.3	3.8	2.4				4.2	3.4	3.0	5	6	2.3			
25	2.3	2.3	3.0	3.2	3	3.5				3.4	3.4	4.8	3.9	6.2	1.7			
26	5.5	2.2	3.8	4	6	2.8				6.1	3.9	2.8	2	3.7	2.5			
27	3.7	3.6	2.6	2.4	2.8	2.5				5.2	5.0	6.1	4	4.5	3.8			
28	8.5	6.5	2.0	3.9	3.8	3.1				3.5	3.6	4.2	3	4.3	2.7			
29	4.7	1.6	3.8	2.6	3	3.3				2.5	3.0	4.5	3.6	4.7	3.7			
30	3.7	6.8	4.4	5.8	3.5	2.5				7.0	5.1	2.6	2.2	3.3	2.1			
31	4.6	6.6	5.5	6	2.8	2.3				1.0	4.8	3.7	2.5	4.3	2.7			
32	5.0	4.0	5.3	3.5	3.4	2.2				6.3	2.5	3.2	4	2.5	3.6			
33	2.0	2.0	3.4	4.3	5	4.7				1.2	6.6	5.2	4.4	2.5	1.4			

34	3.1	4.7	2.3	2.5	4.3	1.4				7.5	2.3	2.5	6	3	2.9			
35	3.7	3.4	3.5	3	3.5	2.6				3.6	5.4	3.0	4	6.3	2.8			
36	4.6	4.3	6.2	4.2	1.5	2.2				5.0	2.5	1.5	7	3.2	3.4			
37	6.4	2.0	3.3	2.8	4	2.3				5.5	6.5	3.4	3.7	3.6	3.3			
38	2.4	4.4	3.5	3	2.5	4.2				6.3	3.4	3.1	5.1	2.9	3.8			
39	3.1	5.6	5.2	2.4	2.8	3.6				7.0	6.0	6.1	4.7	5.7	2.4			
40	7.5	4.0	5.7	3	2.6	2.7				4.7	3.4	6.4	2.8	4.6	3.6			
41	2.9	2.5	1.3	2.5	4	3				4.9	3.5	1.9	2.3	3.1	4.2			
42	6.2	2.9	4.8	1	2.5	1.9				2.7	5.1	5.5	3.7	2.7	4.7			
43	1.8	4.1	8.0	4.2	2.8	4.8				3.2	3.9	2.7	6	3.2	2			
44	4.5	2.1	4.1	4.2	3	2.1				3.2	3.7	5.5	5.6	3.7	2			
45	3.5	4.9	3.7	3.8	2.5	3.2				3.6	3.2	3.3	4	2.1	3.1			
46	3.6	2.4	3.5	3.4	3.5	4.5				5.2	5.5	5.5	4.4	4.2	2.9			
47	3.7	2.2	3.2	1.5	4.2	2.4				7.3	3.9	2.4	5.9	3	3.2			
48	6.2	7.7	4.0	2.6	3.3	5.2				8.7	3.6	4.0	2.1	4.4	1.9			
49	2.0	4.0	3.0	2.5	4.3	4				7.3	3.3	2.9	3.2	2.5	2.7			
50	4.5	2.7	3.7	3.9	2.8	3.6				3.0	2.5	5.6	3	4.1	2.6			
51	1.6	2.0	2.7	2.6	2	2.3				1.5	4.3	3.0	3.4	3	2			
52	5.0	3.8	3.2	5.8	4.8	1.9				6.3	6.1	3.9	3.3	4.3	2.7			
53	6.6	3.5	5.0	6	3	2.7				2.2	5.0	2.8	5	5.4	2.5			
54	2.0	4.0	3.0	3.5	1.1	2.3				5.7	5.4	5.3	3.5	4.1	4.5			
55	6.3	2.1	2.6	4.3	4.8	2.8				4.3	2.6	3.2	2.7	4.5	3.5			
56	4.7	2.9	1.1	2.5	2.5	2.7				3.5	4.5	3.6	3	1.9	2.3			
57	4.0	3.1	5.0	3	3.4	5				2.5	2.8	3.0	3.7	2	2			
58	4.1	4.7	6.0	4.2	3.2	1.7				5.0	1.5	5.1	4	2	2.8			
59	2.2	4.6	4.0	2.8	2.4	3.5				3.3	2.6	2.7	3.8	3.3	3.9			
60	3.2	5.0	5.1	3	2.6	3.9				3.5	4.2	2.2	3.2	3.7	4			
61	4.8	4.5	2.0	2.4	2	5.1				4.0	4.2	2.8	4.5	2.7	2.9			
62	2.7	3.5	3.4	3	4	3.4				5.0	3.7	3.5	4.2	4.9	3.1			
63	5.7	2.5	6.7	2.5	2.4	2				2.0	6.3	5.0	3.3	2	4.5			
64	4.2	4.5	8.0	2.9	2.4	2.8				4.0	3.5	3.7	2.9	2.3	2.6			
65	9.5	4.4	5.5	3.2	3.9	5.3				4.2	2.3	6.0	5.8	3.4	3			
66	4.5	5.0	4.0	1.9	3.4	2.2				5.1	2.3	2.5	5	3	2.2			
67	3.2	3.9	4.2	2.7		2.7				5.5	3.5	3.0	2.5	2	5			
68	2.0	5.8	3.4	2.6		2.5				3.7	7.4	2.5	3.5	5	2.3			
69	3.1	4.1	6.0	2		3.2				4.5	4.0	1.7	2.3	2.5	3.7			
70	6.1	6.1	5.8	2.7		2.7				2.3	1.3	4.0	3.4	2	3.7			
71	3.1	1.0	5.0	2.3		2.2				5.6	2.5	2.5	3.3	5.9	2.8			
72	2.5	5.5	5.0	3.7		1.7				7.5	5.2	3.5	1.5	2.2	1.9			
73	2.1	1.8	3.0	3.7		2.3				3.3	3.5	6.0	4	4.7	3			
74	5.7	2.9	4.2	2.8		1.5				4.1	4.7	2.6	3.9	3	3.1			
75	4.0	4.2	3.5	1.9		1.9				3.7	5.6	3.1	2	3.4	2.7			
76	2.0	2.0	4.0	3		2.4				3.8	7.0	3.6	3.1	4.1	1.6			
77	2.5	2.8	2.5	3.1		1.5				9.0	5.5	2.0	4.2	3.3	2.1			
78	3.5	4.5	5.0	4.3		2.7				4.9	6.5	4.0	5.3	4.4	1			
79	2.7	2.0	3.0	2.4		2				3.2	4.8	4.0	2.5	3	1.5			
80	5.7	3.5	6.9	3.2		2.6				7.7	6.4	4.5	6	2.6	2.4			
81	4.2	4.3	2.9			2.7				4.4	4.0	3.2	2.3	4.3	1.9			
82	4.5	2.0	5.1			1.9				3.6	4.6	2.1	3.2	2.5	1.5			
83	5.0	5.9	1.4			3.2				5.4	7.0	3.5	3	2	2.3			
84	6.0	3.0	7.0			2.9				3.2	3.3	4.8	4.2	4	1.7			
85	3.3	4.5	3.5			1.7				4.0	3.5	3.4	1.5	2.5	2.2			
86	3.0	5.9	5.0			2.3				3.7	4.0	2.9	2	4.1	2.7			
87	6.4	4.3	3.5			4.7				3.0	2.6	2.2	4.8		3.2			
88	2.9	7.0	3.0			4				3.3	2.6	2.5	4.4		2.5			
89	4.1	4.5	3.0			2.5				3.2	4.4	4.1	3.1		2.7			
90	1.0	5.4	2.8			3.7				4.2	2.5	3	3.1		4.2			
91	3.6	3.7	4.9			3.1				2.5	4.3	1.5	2		2.4			
92	6.0	1.6	4.0			3.1				3.0	3.5	4	3.7		3			
93	4.5	2.0	5.0			2.3				5.5	5.0	2.7	5.5		1.8			
94	2.0	4.5	2.5			1.6				2.7	3.6	4	5.6		2.9			
95	1.8	4.8	5.0			2.3				3.4	5.5	3.2	4.8		5.4			
96	6.5	5.5	5.8			4.8				4.2	4.2	2.9	4.3		4.1			
97	2.1	5.0	3.5			3				1.5	3.6	5.1	6.4		4.5			
98	6.8	3.4	5.1			4.3				2.5	4.5	5.2	2.6		1.9			
99	8.8	2.0	5.4			3.5				2.6	6.3	3.3	6.3		2			
100	5.8	1.6	3.1			4				3.7	4.3	3.6	3.7		2			
101	3.5	4.1	4.5			5				1.0	3.8	3	4.8		3.3			
102	2.7	2.7	5.8			3.5				3.6	4.5	2	3.2		3.7			
103	5.5	2.7	7.7			5.7				2.9	2.5	3.7	3.1		2.7			

104	7.0	3.3	3.9			4.1				1.5	5.0	5	4.1		4.9			
105	3.5	4.8	4.5			2.8				4.4	3.0	3.5	3.5		2			
106	3.5	4.0	5.4			4.2				2.4	4.5	2.8	3.9		2.3			
107	5.3	0.8	6.4			3.3				5.1	4.5	2.2	5.1		3.4			
108	6.6	2.2	5.0			3.8				5.7	6.1	2.5	3.4		3			
109	5.2	5.5	3.8			2.4				1.7	4.3	3.5	2		2			
110	3.0	4.0	2.2			3				7.5	3.0	4.8	3.5		3			
111	3.8	3.2	3.9			4.3				4.5	4.3	2.8	5		3.7			
112	3.0	3.4	6.3			3.5				2.5	4.5	6.1	3.7		2.9			
113	6.5	2.8	4.5			4				3.0	5.5	4.2	3		3.1			
114	4.7	2.3	6.3			3.9				5.0	4.3	1.9	2.9		1.5			
115	4.2	2.1	5.0			2.6				3.5	3.3	5.5	2.6		4.8			
116	2.8	4.6	6.1			3.3				3.5	4.8	2.7	4.9		2.1			
117	2.6	5.0	7.5							2	3.2		5.9		3.2			
118	4.0	2.2	4.6							3.5	3.4		2.5		4.5			
119	2.5	2.0	3.7							2.7	2.5		5.6		2.4			
120	6.0	6.0	3.9							4.3	3.6		3.7		3.7			
121	4.1	3.4	5.1							3.7	4.2		2		2.7			
122	4.0	2.5	4.3							4.4	2.5		4		3.1			
123	2.0	3.2	5.5							2.7	4.6		3.9		2.9			
124	2.9	3.0	4.6							5.7	5		2		2.1			
125	5.5	2.2	5.0							3	5		3.1		2.9			
126	2.0	5.5	5.0							5.6	4.6		6.4		1.6			
127	3.2	3.9	3.3							2.5	3.6		4.8		2.5			
128	7.6	3.3	1.4							3.2	5.4		5.5		2.4			
129	2.8	3	3.4							3.5	3.9		5.6		3.5			
130	5.8	2.62.2	6.0							4.5	2.6		4		2.8			
131	5.0	4.5	4.7							3.6	1.3		4.4		2.5			
132			8.8							3.4	4		5.1		2.3			
133			6.8							1.7	3.5		4.7		2.8			
134			4.0							2.5	2.5		3.9		2			
135			2.7							5.2	3.3		2		5			
136			4.5							4.9	5.5		4		1.7			
137			2.6							5.7	5.1		3.6		4.2			
138			4.1							5.5	3.6		2.2		3.6			
139			5.0							7.7	3.4				2.7			
140			5.5							5.5	6.1				3			
141			3.7							5.1	3.5				1.5			
142			8.5							1.2	5.6				4.8			
143			4.7							4.2	4				2.1			
144			3.7							6.3	4.2							
145			4.6							1.5	4.5							
146			5							4	3.7							
147			2							4.2	4							
148			3.1							2.9	4.8							
149			3.7							4.3	3.9							
150			4.6							3	4.5							
151			6.4							6.3	3.5							
152			4.5							5.2	6.5							
153			1.6							3.3	4.4							
154			5							7.5	2.5							
155			3.2							4	4.4							
156			2							2.5	2.5							
157			3.1							4.5	2.6							
158			6.1							5.8	4							
159			31							5.5	3.5							
160			2.5							1.2	3.6							
161			2.1							7.3	5.5							
162			5.7							3.5	3.6							
163			4							3.3	4.6							
164			2								2.3							
165			2.5								3.5							
166			3.5								6.3							
167			2.7								3.7							
168			5.7								4.2							
169			4.7								4.2							
170											3.5							
171											4.3							
172											2.5							
173											4.4							

174											2.5							
175											2.6							
176											4							
178											3.5							
179											3.3							
180											4.6							
Average Length (centimeters)	**4.261068702**	**3.628461538**	**4.385798817**	**3.34125**	**3.318181818**	**3.109482759**	**2.266666667**	**2.6**	**2.2**	**4.119631902**	**4.17877095**	**3.628448276**	**3.871014493**	**3.534883721**	**2.946853147**	**3.19375**	**1.96**	**2.133333333**

Growth Cycle 4

COCONUT COIR MAT DATA

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
DATA SETS	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***
Number of Seeds	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500	2500
Total Weight (ounces)	2.7	3.3	2.2	2	2.2	2.1	2.7	2	2.4	3.7	3.1	3.9	2.3	1.6	2	3	2.8	3.2
Stems	1718	1985	1651	1024	1134	1989	164	134	108	1889	1483	1649	1119	1336	1183	120	177	242
Stem Weight (ounces)	1.4	1.5	1.1	0.8	0.8	0.9	0.3	0.2	0.2	1.3	1.2	1.3	1	0.7	0.8	0.3	0.2	0.3
Mat Dry Weight (ounces)	0.8	0.6	0.6	0.7	0.7	0.7	0.7	0.9	0.8	0.8	0.9	0.7	0.9	0.8	0.8	0.9	0.8	0.7
Mat Weight (ounces)	1.3	1.8	1.1	1.2	1.4	1.2	2.4	1.8	2.2	2.4	1.9	2.6	1.3	0.9	1.2	2.7	2.6	2.9
Average Length (centimeters)	5.032163743	5.340909091	4.446060606	4.558415842	4.255752212	4.633333333	3.29375	2.061538462	2.9	4.229946524	4.897297297	5.007317073	4.687387387	4.42481203	4.170338983	3.125	2.676470588	3.575
Relative Humidity (%)	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6	65.6
Temperature Day (Farenheit)	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66	80.66
Temperature Night (Farenheit)	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68	68.68
Germination Rate (%)	**68.72%**	**79.40%**	**66.04%**	**40.96%**	**45.36%**	**79.56%**	**6.56%**	**5.36%**	**4.32%**	**75.56%**	**59.32%**	**65.96%**	**44.76%**	**53.44%**	**47.32%**	**4.80%**	**7.08%**	**9.68%**

TENT CONDITIONS

TENT HUMIDITY						
	Day					
Time of Day	**1**	**2**	**3**	**4**	**5**	**Average**
Day	64	63	64	67	70	**65.6**
Night	89	99	96	99	99	**96.4**

TENT TEMPERATURES						
	Day					
Time of Day	**1**	**2**	**3**	**4**	**5**	**Average**
Day	80.2	80.1	80.4	81.3	81.3	**80.66**
Night	68.5	68.4	68.7	68.9	68.9	**68.68**

STEM LENGTHS

	CocoTek (1/4 inch)									Envelor (1/2 inch)								
	Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum			Treatment: Only Seeds			Treatment: Pocket			Treatment: Konjac Gum		
	Sample #1	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***	***Sample #1***	***Sample #2***	***Sample #3***
Stem Lengths (centimeters)																		
1	4.1	6.2	6.3	5.3	6.5	3.2	1.6	1.7	2.8	5.7	4.9	6	4.3	5.7	5.5	3.7	3.2	4
2	5.5	5.9	3.5	9.6	4	4.2	3.6	1.7	2.5	2.6	7	4.1	5.5	3.1	3.7	3.8	2.5	3.0
3	8.0	6.1	3.6	4.3	5.1	4.6	3.3	3.1	3.8	4.9	6.3	6.4	4.7	3.2	3	1.5	2.2	2.5
4	4.8	5.1	4.5	6.3	3.9	4.7	2.1	3.7	3.1	6.0	4.5	7.5	4.5	3.5	6.2	4.3	5.0	4.7
5	6.7	4.2	5.2	4.8	4	4.5	4.1	1.5	1.9	4.5	6.8	6.0	8.5	5.2	6.3	3.4	1.9	5.1
6	6.6	4.4	4.7	3.6	3.9	3.5	2.2	1.9	2.8	5.5	6.2	2.8	3.6	4.5	5.6	4.1	3.4	4.2
7	6.9	3.3	2.5	7	5.5	3.6	4	1.6	4.3	6.2	8.4	4.8	3.8	3.6	4.3	2.2	2	3.3
8	4.2	3.6	2.4	5.2	4.7	4.8	3.3	1.6	2.3	3.5	3	4.5	5.9	6.8	5.5	2.5	2.7	2.0
9	4.4	5.2	6.5	5.1	6	7.5	3.5	1.5	2.9	4.5	4.3	4.5	6.5	3.1	5.9	2.7	3.4	3.2
10	4.5	5.2	3.7	3	3.2	3.6	2.7	1.4	2.6	3.8	6.1	4.6	8	3	2.5	3.3	2.2	3.8
11	3.3	5.6	2.5	4.4	6.3	2.5	3.8	2.7		4.1	2.6	3.2	3.6	4.3	2.6	3.1	2.3	6.4
12	6	4.3	3.6	6.8	2.6	5.7	3.1	2.9		2.5	4.7	3.1	6.5	3.1	3	2.9	2.4	3.9
13	8.9	3.5	3	2.9	5.1	3.1	3.6	1.5		4.8	5.8	4.1	4.5	3	5.8		1.9	3.4
14	7.2	3.2	4.5	4	5.9	3.2	3.5			3.1	3	5.2	8.2	5.8	4.6		2	5.5
15	7.0	2.4	5.5	3.5	5.5	3.5	5.7			6.0	6.6	3.9	5.9	4.8	2.8		3.4	4.8
16	8.2	3.9	9	2	3.9	5.2	2.6			4.1	4.1	6.5	3	4.9	3.2		2.3	3.5
17	3.7	5.8	4.5	5.4	4.3	4.5				3.2	5.7	6.4	4.5	8	5		2.7	3.1
18	5	7.2	8.0	5.6	4.5	3.6				6.8	6.0	2.4	5.4	2.5	2.1			4.5
19	3.1	7.2	5.5	7.5	6.3	6.8				5.2	4.8	5.4	4.5	4.3	4			2.5
20	5.2	6.3	2.6	3.7	4.7	3.1				3.4	4.0	6.1	5.3	5.5	4.7			3.4
21	5.6	3.3	5	3.6	6.2	4.8				1	6	3.5	4.9	5.7	3.4			2.9
22	7.9	8.9	4.2	4.3	4.6	4.9				3.6	3.3	5.2	5.7	1.4	3			1.7
23	5.1	8.5	5.2	6.7	4.2	8				4	4.5	5.2	5	5.5	3.7			2.7
24	3.5	7.8	3.6	4.8	4.8	2.5				7.3	8.2	4.0	4	8.9	4.3			1.7
25	5.7	3.9	5.7	3.8	4	4.3				2	2.7	1.7	3.4	6.3	4.1			
26	5.8	4.8	3.6	4.3	2	5.5				2.1	4.8	4.2	6.7	4.9	2.5			
27	3.2	5	5.5	3.8	4.5	5.7				6.7	6.4	4.3	6.5	1.8	3.7			
28	3.1	6.4	3.1	3.3	2.9	1.4				8.3	5.5	5	2.1	5	3.8			
29	8.2	3.6	5	3.6	2.6	5.5				3.3	6.8	7	3.2	3.2	3			
30	6.3	4.2	2.6	6.8	2.5	6				5.7	6	3.3	3	4.2	2.2			
31	5.5	5.6	3.2	3.9	3.3	6.8				4.9	4.3	3.1	5	4.6	5.5			
32	6.8	5.5	4.2	5.2	2.8	7				3.2	4.7	4.3	4.5	4.7	3.7			
33	4.4	4.8	3.5	4.7	4	3.6				6.8	7.2	6.8	4.9	4.5	3.2			

34	6	4.2	4.9	6.5	4.9	5.5				5.5	5.4	6.1	4.3	2.5	3.4			
35	2.5	5.6	3.5	5.2	5.4	3				3	7.8	4.0	4.7	3.6	2.3			
36	6	6.2	5.8	4.2	4.4	4.7				6.5	6.7	4.5	6.8	4.4	2.5			
37	5.2	6.0	4.7	6	2	4.9				3	2.5	3.7	6.5	6	2.3			
38	4.3	4	3.5	2.5	3.3	4.1				3.9	7.5	3.2	4.5	5.2	3.1			
39	6.7	53	2.9	4.2	4.5	7.2				2.5	6.0	3	3.5	3.6	3.7			
40	5.7	2.1	4.6	3.1	2.5	3				7	4.7	5	2.5	5.5	1.5			
41	4.1	7.5	4.4	4.2	2.4	5.2				4.4	4.6	5.4	3.3	3.9	3.9			
42	5.2	7.5	3.9	5.1	2.5	6.5				2.8	6.8	6.4	3.4	4.5	2.7			
43	7.5	5.3	4.3	5.8	1.3	6.8				5.3	4.6	3.4	4.5	6.6	5.4			
44	4.5	4.8	5.5	5.2	6.5	4.8				4	6.2	3.5	6.5	4.7	4.4			
45	4.9	4.6	5	4.3	6.3	5.2				3.5	3.2	3.7	4.6	4.7	4.5			
46	3.2	5.3	4.2	4.3	4.5	4				3.7	5.6	2.9	4.3	5.2	2.9			
47	6	8	3.2	5.9	2.5	7				3.7	3.1	3.6	6.1	5.7	2.6			
48	6.2	8	2.9	4.5	3.2	6.8				8	4.7	7.3	5	3.2	2.5			
49	4.5	3.1	4.6	4.7	2	6				3.5	3	4.8	5.8	2	3.3			
50	4.7	5.5	3.3	2.5	2.4	6.5				7.0	4.3	3.3	5.5	5.2	2.8			
51	3.2	5.5	4.6	6.3	1.3	2.4				3.9	3.5	4.2	6	4	4			
52	3.0	5	4.8	3.7	2	5.6				4.6	7.5	4.3	1	4.5	4.9			
53	3.6	4.9	4.5	4.2	4	5.3				5	4.1	2.1	4.4	5.7	5.4			
54	5.3	5.5	4.3	5.1	4.8	5				2.4	3.4	2.4	5.4	4.4	4.4			
55	2.5	4.7	4.5	7.5	4.2	3.5				2	7	6.4	6.5	6.4	2			
56	5.1	3.5	6	4.5	4.6	3				5.9	6.4	4.2	4.7	4.3	3.3			
57	6.2	4.9	4.5	3.3	6.2	3.1				4.6	3.7	5.1	3.5	3.7	2.5			
58	3.8	7.5	4.0	5.7	4.7	4.3				5.2	3.8	4.9	3	6	2.4			
59	4.3	4.7	3.3	4.1	6.3	4				4	4.8	4	4.1	4.4	2.5			
60	3.7	5.0	5.1	3.9	4.3	3.8				3.1	2.1	4.4	4.5	3	1.3			
61	1.8	3.2	5.0	3.7	4.5	2.5				3.4	4.4	4.5	3.7	4.1	6.5			
62	1.8	7.7	4.3	5.2	3.9	5.7				2.8	4.5	2.5	3.2	3	2.5			
63	6.5	3.9	4.8	3.6	5.5	3.7				2.1	6.8	5.5	2	3.6	6.3			
64	4.8	6	4.3	3.7	5.9	4.5				5.3	3	5.2	2.4	3.6	3.7			
65	4.7	5.8	3	3.5	5.1	2				4.5	5.2	3.5	1.3	2.9	4.2			
66	5.2	4.5	3.8	4.8	2.6	4.6				2.5	5.2	3.6	3.1	3.7	5.1			
67	5.1	4.7	3.6	5.3	6.3	3.2				5.2	2.3	4.2	5.5	3.5	7.5			
68	4.7	3.1	5	1.5	6.5	4				4.5	4.2	5.7	5.2	3.4	4.5			
69	4.8	3	5.7	5.3	3.9	5.8				4	5.3	1.6	6	6.4	3.3			
70	4.6	7.5	6.4	4.4	3.3	6				2.4	4.5	4.6	4.5	5.4	5.7			
71	3.9	5.7	5.2	5.4	3.9	5.6				3	3.7	2.6	5.3	5	4.1			
72	2.3	7	6.3	6.5	4.6	6.8				4.2	4.8	6.6	6.3	3	3.9			
73	5	3.6	3.6	4.7	2	6.1				6.3	3.2	7.5	5.5	3.2	3.7			
74	4.1	4.5	5.5	3.5	4.4	4.1				3.5	2.6	2.6	6.3	3.7	5.2			
75	7.2	3.5	3.9	3	4.8	3.3				3.4	6.1	6.1	2.7	4.5	3.6			
76	5.5	4.3	4.5	4.7	4.8	2.9				5.4	5.8	5	9.7	4	3.7			
77	3.2	4.3	2.5	4.5	4.5	4.5				2.9	6.6	2.5	4.4	6.1	3.5			
78	1.7	4.3	3.6	3.7	6	5				2	4.7	3.8	3.4	6.8	4.8			
79	8.9	4.0	4.4	1.5	4	3				2.4	4.7	4.0	5.5	4.3	5.3			
80	6.3	2.5	6	4.3	2.5	6				4.7	5.2	5	4.2	3.6	1.5			
81	4.9	4.1	5.2	3.8	3.2	8.2				2	3.0	1.9	3.3	6.4	4.3			
82	1.8	7.2	3	4.2	2	4.5				4.3	4.3	3	5.9	5	6.3			
83	5.0	5.5	3.1	4.5	2.4	3.7				4.5	3.1	4.6	4.3	4.8	5.5			
84	6.0	3.2	4.3	3.6	5.9	2.3				5.5	3	6	4.5	3.9	4.8			
85	8.2	1.7	4	3.6	2.6	4.3				5.5	5.8	3.9	4.3	7.8	5			
86	4.5	8.9	4.5	4.3	3.2	6.4				3	4.9	4.3	5.2	8.5	5.8			
87	4.3	6.3	5	3.9	6	5.3				4.3	6	7.3	4.8	3.3	5.2			
88	2.3	4.9	5.5	4.7	4.7	4.9				5	7.8	5.5	5.1	6.3	7.6			
89	7	1.8	3.3	5.2	5.5	5.7				2.2	3.5	3.8	4.2	7.2	5.2			
90	6.8	5	6.3	3.9	4	4				4.5	4.2	5.2	3.1	7	3.3			
91	6	7	5.5	6.8	5.1	3.7				4.4	6.2	3.1	4.2	5.8	4			
92	6.5	6.8	2.6	3.6	4	5.7				5.5	4.5	3.6	2.5	3.9	5.6			
93	8.2	6.0	5.0	3.3	6.5	4.6				4.6	4.7	2.5	6	2.4	6.2			
94	4.4	6.2	5.1	3.8	6.5	4.5				6	6.4	2.5	4.2	3.2	5.5			
95	6.2	3.2	3.5	4.3	1.4	6.4				3.4	4.8	4.6	5.2	6	6			
96	4.8	4.2	9	3.8	2.2	2.5				5.1	4.7	6	6.5	4.5	5.9			
97	3.7	4.6	3.2	4.8	6.5	4.1				4.6	6.8	6.4	1.5	4.3	4.4			
98	4.4	4.7	5	6.7	5.5	5.5				5.5	3.2	6.1	5.3	4.5	4.2			
99	6.2	4.5	5	4.3	5.5	3.9				3.6	4.4	3.3	4.8	4.8	1.2			
100	4.8	3.5	3.6	3.6	5	4.5				3	4.7	5.2	3.5	4.6	5			
101	5	3.6	4.5	3..7	4.5	5.5				4.1	3	4	3	3.3	4.6			
102	6	4.8	4.2	5.6	6.2	4.1				3	4.3	4.8	5.1	4.6	2.8			
103	4.5	7.5	4.2		6.3	5.3				4.4	3.5	4	5.2	2.9	5.1			

104	4.7	3.6	4.3		3.5	2.7				6	7.5	5.4	7	3.2	2.7			
105	3.1	2.5	4.5		4.5	5.7				3.7	4.1	4.2	3.6	4.2	7			
106	2.5	2.4	8		6.3	5.4				4.3	3.4	4.6	4.8	5	6.3			
107	4.7	5.6	3.5		1.7	4.3				6.4	7	3.2	6.3	5.5	3.5			
108	5.2	5.3	3.2		4.3	2.3				4.4	6.4	5	4.3	4.3	6.7			
109	8	5	4.3		4.6	6.4				5.7	3.7	3.7	3.5	3.9	6.2			
110	5.2	3.5	3.7		2.8	6.1				4.5	3.8	4.4	3.4	5.2	6.1			
111	6	4.3	5.7		4.6	3.3				4	4.8	7.5	5	3.6	4.3			
112	3.2	6.4	4.6		4.2	3.5				5.2	2.1	5.2		4.5	4.9			
113	5.1	3.4	4.3		3.4	5				2.0	4.8	4.1		4	4.5			
114	4.8	4.9	5.7			3.7				3.2	4.5	3.1		2.4	5			
115	5.6	7	6.5			4.4				5.7	6.8	3.2		3	3			
116	5.2	3.9	3.6			6.2				6.8	3	4.6		4.2	3.2			
117	3	5.5	2.9			4.8				4.7	5.8	4.5		6.3	2.1			
118	4.7	8	4.5			2.8				5.3	6.1	4.5		3.5	5.6			
119	6.7	3.2	5			4.8				1.5	2.6	4.8		3.4				
120	7.9	4.3	2.4			3.1				5.2	3.2	2.8		5.4				
121	4.3	5.6	4.2			7.7				3	4.8	6		2.9				
122	3.6	5	4.7			4.3				3.5	3.7	7.5		2				
123	4.8	7.5	4.6			4.5				3.9	4.5	6.4		2.4				
124	6.6	3.5	3.8			5				4	5.3	4.1		4.7				
125	5.1	7.5	4.7			5.5				2.4	4.2	6		2				
126	6.7	5.8	2.6			3.3				4.1	2.3	2.5		4.3				
127	5.3	4.8	3.5			1.5				5.3	5.2	5		4.2				
128	4.6	8	4.9			3.1				2.6	5.2	6.1		5.3				
129	6.9	7.7	2.9			3.3				5.1	4.3	2.6		4.5				
130	3.5	4.3	4.8			7				4.2	6	74.5		3.7				
131	5.7	5.9	4.5			5				4	5.8	6.6		4.8				
132	5.5	7.2	8			4.3				1.4	5.5	2.6		3.2				
133	3.9	4.2	3.5			4.9				3.1	6.4	4.6		2.6				
134	4.2	3.1	3.2			5.7				4.9	4.8	1.6						
135	5.8	3.9	4.3			3.3				2.7	2.7	5.7						
136	5.2	4.3	3.5			8.3				1.6	8.2	4.2						
137	6.2	6.1	4.5			6.7				2.7	4.5	3.6						
138	5	6.3	4.2			2.1				5.5	3.3	3.6						
139	4.5	5.6	6.0			2				3.6	6	5.2						
140	5.8	5.5	4.5			7.3				4.8	4	5.5						
141	5.2	6	4.3			4				4.9	4.8	6.3						
142	6.2	4.2	4.5			3.6				8	6	8.2						
143	3.3	3.6	4.8			1				2.5	5.7	3.1						
144	3.1	7	4.6			3.4				4.3	4.1	3.2						
145	7.5	5.7	3.3			5.2				5.5	6.6	5.8						
146	3.8	7.5	4.6			6.5				5.7	3	5.7						
147	6	3	2.9			3				1.4	5.8	3.5						
148	8.2	3.4	3.2			5.5				5.5	4.7	5.1						
149	4.5	3.1	4.2			6.8				3.1		7.9						
150	4.3	4.7	5			3.2				3.2		5.6						
151	1.8	4.5	5.5			5.5				3.5		5.2						
152	3.7	5.8	4.3			4.6				5.2		3.1						
153	4.3	6	3.9			5.1				4.5		5						
154	3.8	3.9	3.6			3.4				3.6		3.7						
155	6.2	7.7	5.7			6				6.8		8.2						
156	5.1	3.2	3.6			4.6				3.1		7						
157	2.5	5	5.2			5.5				5.7		7.2						
158	5.3	4.7	4.2			4.4				6.8		4.6						
159	3.6	4.8	5			4.5				3		4.7						
160	3	5.3	2.6			2.2				4.6		5.2						
161	3.2	7.5	5.5			5				4		4.8						
162	4.7	7.5	4			4.3				3		1.7						
163	4.5	2.1	6			3				3		4.5						
164	6.2	5.3	4.5			5.5				5.3		4.1						
165	6	4	6.2			5.5				2.7								
166	3.2	6				4.5				3.8								
167	4.5	6.2				4.8				6.7								
168	4.4	5.6				5.3				4								
169	4.2	4.2				7.5				2.8								
170	6.9	4.8				2.1				2								
171	6.6	5.5				5.3				6								
172		5.6				4				4.5								
173		4.2				6				4.1								

174		3.5				6.2				6.8								
175		4.3				5.6				4.7								
176		5.6				4.2				5.3								
178		5.2				4.8				1.5								
179		5.2				5.5				5.2								
180		3.6				5.6				3								
181		**3.3**				4.2				**3.5**								
182		4.4				4.2				3.9								
183		4.2				5				4								
184		5.1				5.5				2.4								
185		6.1				4.3				4.1								
186		5.9				3.9				5.3								
187		6.2				4.3				2.6								
188		7.5				3.8				5.1								
189		4.9				6.2												
190		3.5				5.1												
191		4.7				2.5												
192		7.2				5.3												
193		7				3.6												
194		8.2				3												
195		3.7				3.2												
196		5				4.7												
197		3.1				4.5												
197		5.2				6.2												
198		5.6				4.4												
Average Length (centimeters)	**5.032163743**	**5.340909091**	**4.446060606**	**4.558415842**	**4.255752212**	**4.633333333**	**3.29375**	**2.061538462**	**2.9**	**4.229946524**	**4.897297297**	**5.007317073**	**4.687387387**	**4.42481203**	**4.170338983**	**3.125**	**2.676470588**	**3.575**

Appendix C- Growth Cycle Images

The growth cycle images were taken during the germination study to document the samples growth. The images are separated by trial, mat type, sample, and treatment as well as labeled by the day in the growth cycle they were taken.

Trial 1 Straight Seeds- CocoTek

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 1 Straight Seeds- Envelor

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 1 Pocket- CocoTek

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 1 Pocket- Envelor

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 1 Konjac Gum- CocoTek

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 1 Konjac Gum- Envelor

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 2 Straight Seeds- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

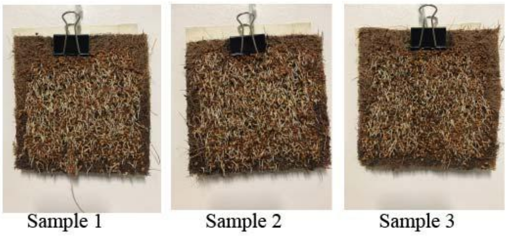
Sample 1 Sample 2 Sample 3

Trial 2 Straight Seeds- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2



Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 2 Pocket- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 2 Pocket- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

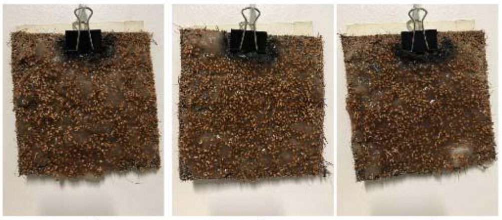
Sample 1 Sample 2 Sample 3

Trial 2 Konjac Gum- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2



Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

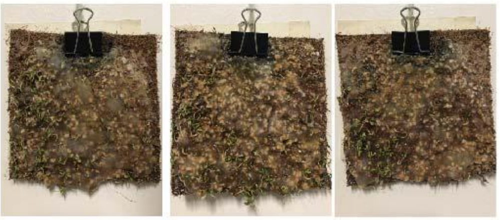
Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6



Sample 1 Sample 2 Sample 3

Trial 2 Konjac Gum- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 3 Straight Seed- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Trial 3 Straight Seeds- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Trial 3 Pocket- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

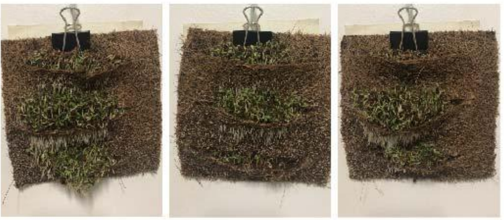
Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6



Sample 1 Sample 2 Sample 3

Trial 3 Pocket- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 3 Konjac Gum- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 3 Konjac Gum- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Day 6

Sample 1 Sample 2 Sample 3

Trial 4 Straight Seeds- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Trial 4 Straight Seeds- Envelor

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Trial 4 Pocket- CocoTek

Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3

Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Trial 4 Pocket- Envelor

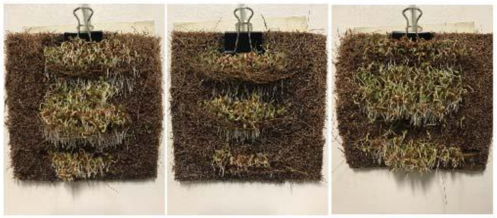
Day 1

Sample 1 Sample 2 Sample 3

Day 2

Sample 1 Sample 2 Sample 3

Day 3



Sample 1 Sample 2 Sample 3

Day 4

Sample 1 Sample 2 Sample 3

Day 5

Sample 1 Sample 2 Sample 3

Trial 4 Konjac Gum- CocoTek

Day 1


Sample 1


Sample 2


Sample 3

Day 2


Sample 1


Sample 2


Sample 3

Day 3


Sample 1


Sample 2


Sample 3

Day 4


Sample 1


Sample 2


Sample 3

Day 5


Sample 1


Sample 2


Sample 3

Trial 4 Konjac Gum- Envelor

Day 1


Sample 1


Sample 2


Sample 3

Day 2


Sample 1


Sample 2


Sample 3

Day 3


Sample 1


Sample 2


Sample 3

Day 4


Sample 1


Sample 2


Sample 3

Day 5


Sample 1


Sample 2


Sample 3

Appendix D- Bioinspiration

Coconut Leaf Sheath

Nature has an abundance of naturally occurring structural patterns. These patterns reoccur in different contexts and can include spirals, fractals, and even weaves. Coconut leaf sheath of the coconut palm (*Cocos nucifera*) is an example of a fibrous mat formation in nature which looks like a woven structure. The coconut leaf sheath is located at the base of the leaf stalk attached to the tree trunk (Figure A1). The leaf sheath has a function of thermal protection for the plant by trapping air between the woven fiber bundles (Oushabi, 2015).

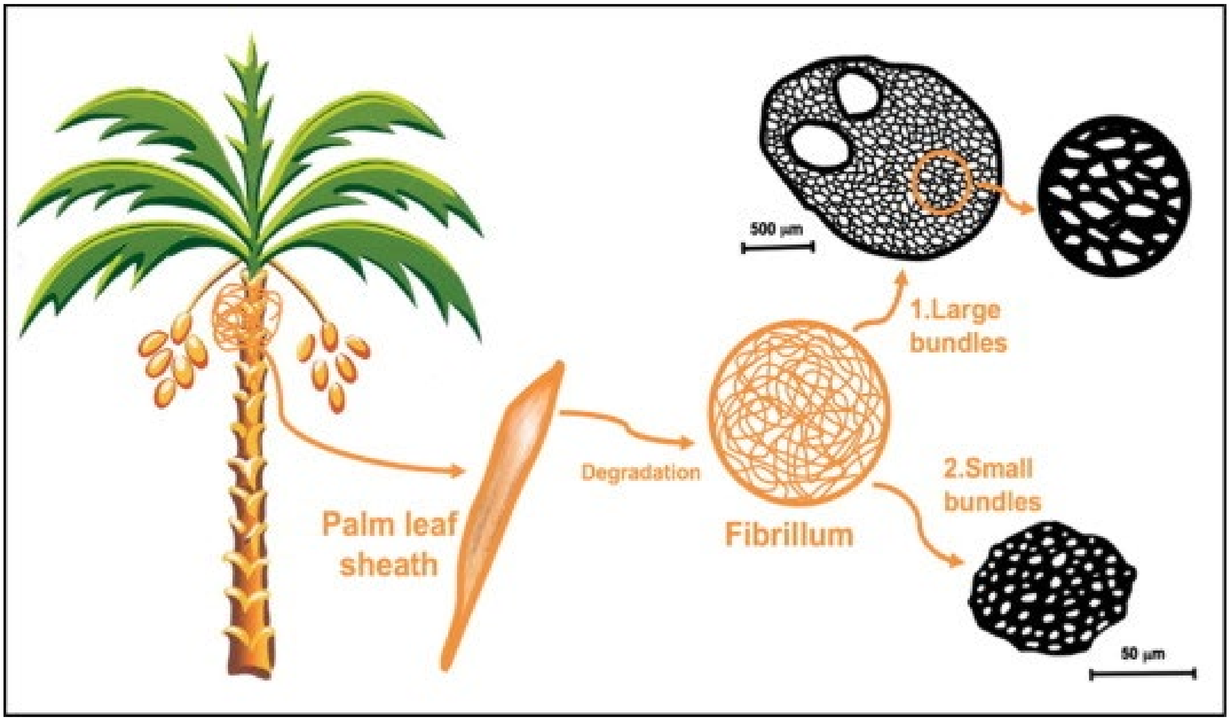


Figure A1: Diagram of palm leaf sheath location (Bourmaud, 2017).

The leaf sheath consists of three types of fibers made mostly of cellulose and lignin. The naturally occurring lignin is important to this woven textile to lend rigidity and discourage rot while cellulose maintains plant stiffness. The fibers are arranged in a particular pattern to impart certain mechanical characteristics to the structure. The fibrous network of the naturally woven textile contains two sets of parallel fibers oriented almost orthogonally to each other, which can be seen in manufactured woven structures (Figure A2). The simplicity of the structure is integral to its design. These parallel coconut fibers emulate the simplicity found in the warp and weft of manufactured woven textiles. The fibers of the coconut are used to enhance the strength and integrity of the natural structure (Das, 2015). Natural textile structures are valued for their low weight, flexibility, and mechanical properties (Eadie, 2011). These valuable traits are the reason these fibers are often used in carpets, mats, and even infused in plastics or cement as fillers or reinforcement. The woven structure of the coconut leaf sheath gives vital inspiration for a textile using coconut coir. A coconut coir textile could be manufactured by imitating the natural woven pattern of the coconut leaf sheath.

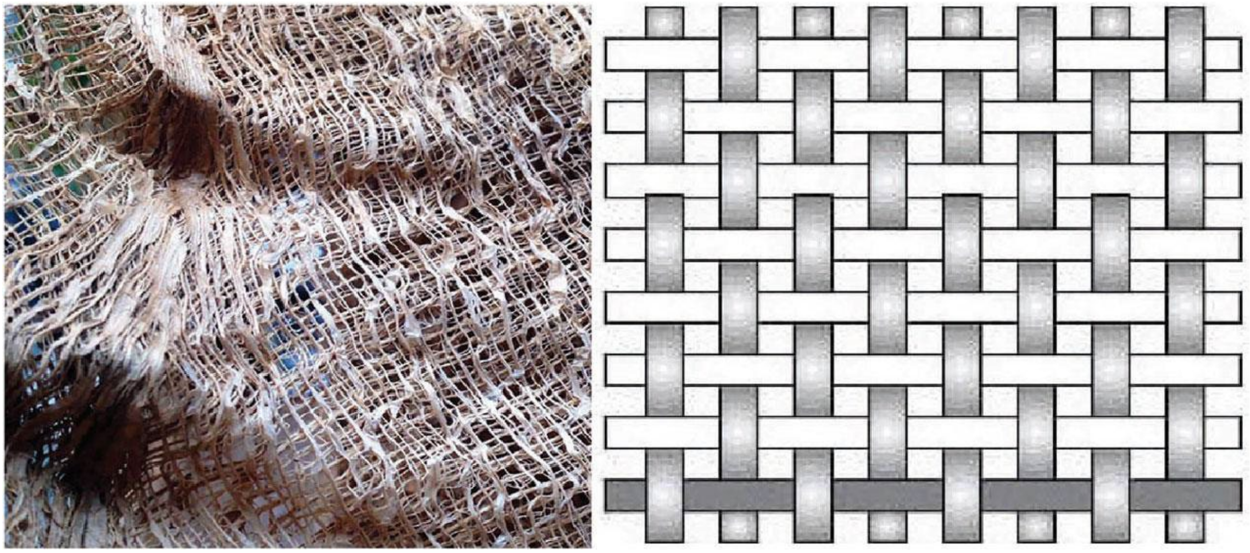


Figure A2: Coconut leaf sheath (left), plain weave structure (right) (Das, 2017)