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Plantastic Pods: The Grow Stick Rooting Revolution for Seeds & Cuttings!

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1 Introduction

1.1 Literature review

Cultivating plants from seeds or cuttings is a fundamental aspect of gardening and agriculture. While traditional methods have been practiced for centuries, there is a persistent need for innovative and efficient approaches to enhance plant growth and development. This section explores the challenges associated with traditional propagation methods and examines potential solutions offered by emerging technologies and materials.

Plant propagation is necessary to allow efficient multiplication and distribution of desirable plant varieties (Sorensen & Garland, 2024). Plant propagation is the process of creating new plants. There are two primary methods of propagation: sexual and asexual.

- Sexual propagation involves the union of pollen and egg, drawing genetic material from two parent plants to create a new, genetically diverse offspring. This process utilizes the floral parts of a plant.
- Asexual propagation, on the other hand, involves taking a part of a single parent plant and inducing it to regenerate into a new plant. The resulting offspring is genetically identical to its parent. This method utilises the vegetative parts of a plant, such as stems, roots, or leaves.

One emerging technology that has garnered attention in this field is the use of cocopeat, a sustainable growing medium derived from coconut husks (Pane et al. 2021). Cocopeat has been extensively studied as a potential alternative to peat moss in plant propagation (Gericke, 1940). It offers a favourable balance between air porosity and water holding capacity, promoting root development and nutrient uptake (Kalaivani and Jawaharlal, 2019). Furthermore, cocopeat is a renewable and environmentally-friendly resource, making it an attractive option for sustainable seedling cultivation.

Research has shown that the use of cocopeat as a growing medium can enhance the growth of both vegetables and various ornamental plants, such as Impatiens. The biostimulant effect of the Trichoderma atroviride fungus, which can readily colonize coir, has been observed to increase aboveground biomass, flower production, pigments, and nutrient concentration in these plants (Traversari et al., 2024).

1.2 Challenges in Traditional Propagation

Traditional methods of plant propagation, such as seed sowing and cutting propagation, face numerous challenges that can hinder successful plant establishment. For instance, seed germination rates can be inconsistent, influenced by factors such as seed quality, soil conditions, and environmental variables. This inconsistency is particularly evident in crops like soybeans, where seed dormancy can delay germination and reduce overall rates. Factors contributing to soybean seed dormancy include seed coat impermeability and the presence of germination inhibitors (Yeli, 2022). Additionally, soybean seeds are susceptible to seed-borne diseases caused by fungal and bacterial pathogens, which can compromise seedling health and vigor (Roberto and Colombo, 2020). Nutrient imbalances further complicate the propagation of soybeans, as specific nutrient requirements must be met to ensure optimal germination and growth (Pane *et al.,* 2021).

Similarly, the propagation of succulents presents its own set of challenges. The delicate nature of succulent tissues makes them particularly sensitive to damage during propagation, especially when employing methods such as cutting or leaf propagation (Traversari *et al.,* 2024). Overwatering or inadequate drainage can lead to root rot, a prevalent issue that significantly impacts the success of succulent propagation (Kalaivani and Jawaharlal, 2019). Furthermore, many succulent species exhibit slow growth rates, which can prolong the propagation process and limit the feasibility of large-scale production (Krishnapillai, *et al.* 2020). These challenges collectively contribute to increased production costs, higher labor demands, and potential plant losses, underscoring the need for innovative propagation solutions (Roberto and Colombo, 2020).

Additionally, the interaction between cocopeat and other potential additives, such as water retention polymers and fertilizers, within the formulation of a cocopeat growth medium remains largely unexplored.

1.3 Alternative Propagation Methods

To address the limitations of traditional propagation, researchers and growers have explored various alternatives. According to Yeli (2022) hydroponics and aeroponics offer controlled environments for plant growth, but they can be complex and resource-intensive. Tissue

culture provides a sterile environment for rapid plant multiplication, but it requires specialized equipment and expertise.

Soilless growing media, such as cocopeat, have gained popularity due to their water-holding capacity and good aeration. Studies by Yau and Murphy (2000) have demonstrated the potential of cocopeat for various plant species. However, the use of cocopeat alone may not provide optimal conditions for all plants, and additional nutrients and support structures may be necessary.

1.4 Soy Beans

The ***Growth stages of soybeans*** is divided into vegetative growth stages (V) and reproductive growth stages (R). Subdivisions of the V stages are designate numerically as V1, V2, V3, through V(n); except the first two stages, which are designated as VE (emergence) and VC (cotyledon stage). The last V stage is designated as V(n) where (n) represents the number for the last node stage of the specific variety (Table 1).

Table 1 Growth Stages of soybeans

Vegetative Stages	Reproductive Stages
VE - Emergence	R1 – Begin Bloom
VC - Cotelydon	R2 – Full Bloom
V1 – First Node	R3 – Beginning Pod
V2 – Second Node	R4 – Full Pod
V3 – Third Node	R5 – Beginning Seed
V4 – Fourth Node	R6 – Full Seed
V5 – Fifth Node	R7 – Beginning Maturity
Vn – nth Node	R8 – Full Maturity

The vegetative growth stages are explained in Table 2.

Table 2 Vegetative Growth Stages

Emergence (VE)	**Soybean emergence typically occurs within 5-10 days after planting, influenced by factors like temperature and moisture.** The initial growth stages involve seed germination, root development, and the emergence of the seedling above the soil surface through the elongation of the hypocotyl.

Emergence (VE)	**Upon emergence, the soybean seedling's hypocotyl straightens, lifting the cotyledons above the soil surface.** This upward movement is driven by the elongation of the hypocotyl.
VC - Cotelydon	**Following emergence and straightening of the hypocotyl, the unifoliolate leaves (first true leaves) unfold, marking the VC stage.** During this initial growth phase, the cotyledons function as the primary nutrient source for the soybean plant.
V1 – First Node	**The subsequent growth stage, following the VC stage, is marked by the development of the first trifoliate leaf.** The numbering system for these vegetative stages, denoted as V stages, is based on the count of fully developed trifoliate leaves on the main stem.
V2 – Second Node	**At the V3 growth stage, soybean plants reach an approximate height of 15-20 cm with three sets of fully developed leaves.** The symbiotic relationship with nitrogen-fixing bacteria commences, marked by the formation of nodules primarily within the upper 25 cm the soil. Healthy nodules exhibit a pink or red interior.
Third to Fifth nodes (V3-V5)	**At the V3 growth stage, soybean plants typically reach a height of 17-23 cm with three fully expanded leaf sets.** As growth progresses to the V5 stage, plant height increases to approximately 25-30 cm, accompanied by the development of six fully expanded leaves. Branching may occur at this stage, especially in wider planting configurations or with lower plant densities.
Sixth node (V6)	**At the V6 stage, soybean plants reach a height of approximately 30 to 35 cm.** They possess seven sets of fully expanded leaves and have likely shed their cotyledons. The plant's growth rate is rapid, with new leaves emerging every two to three days.

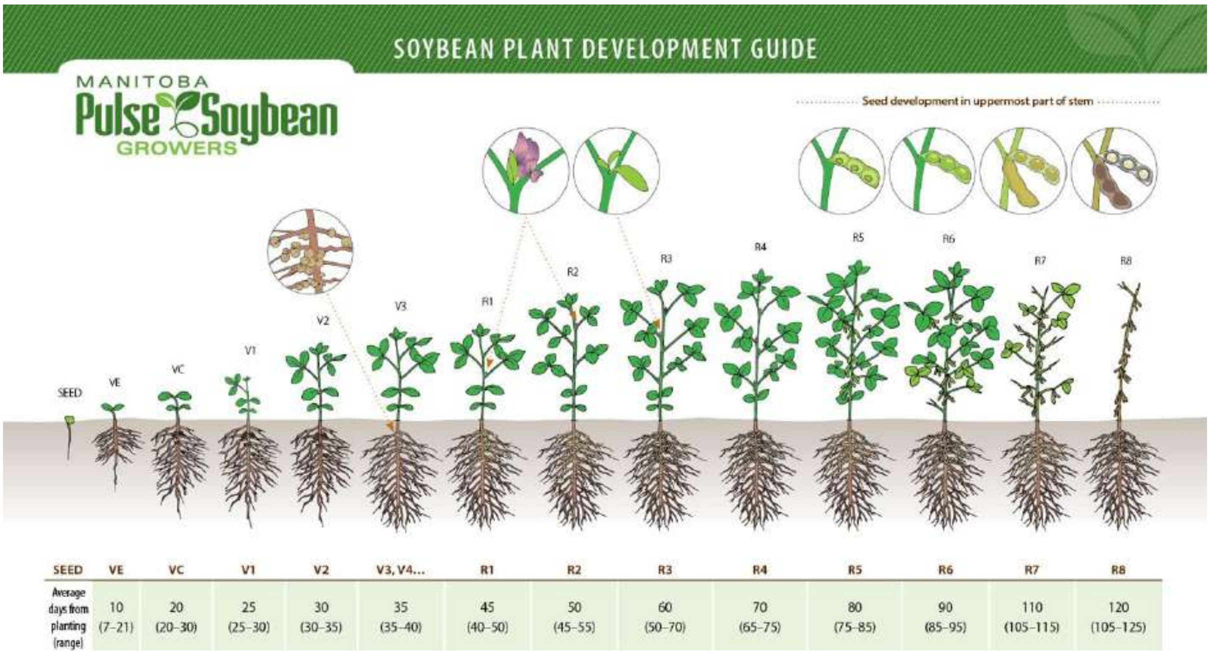

Figure 1 Soybean development (Source: Manitoba Pulse and Soybean Growers)

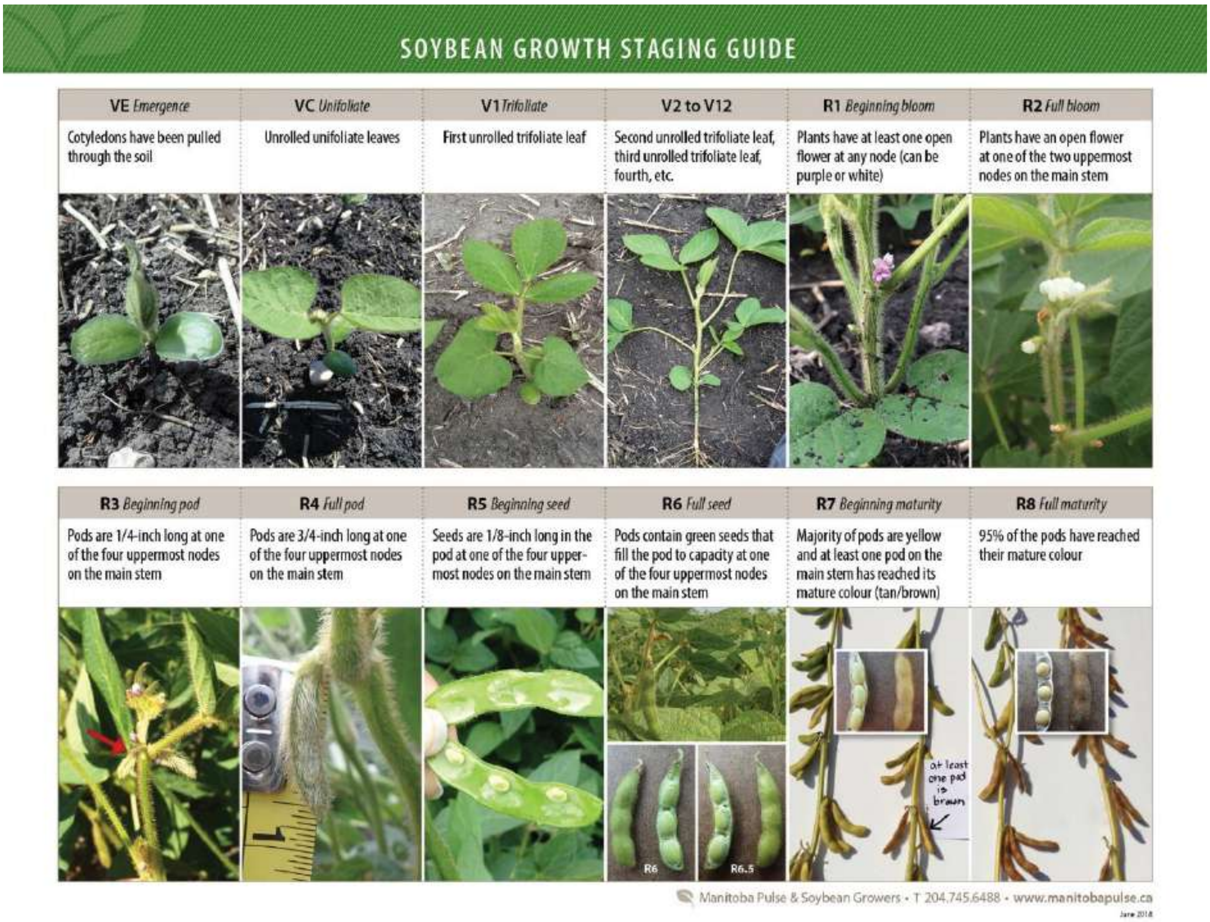

Figure 2 Soybean growth staging guide (Source: Manitoba Pulse and Soybean Growers)

1.5 Propagation of Cuttings

Plant propagation, the process of creating new plants from existing plant material, is a fundamental aspect of horticulture and agriculture. Cuttings, derived from various plant parts, offer a convenient and efficient method for multiplying desirable plant varieties. This literature review explores the techniques and challenges associated with propagating plants from cuttings. The practice of propagating plants from cuttings dates back centuries. Ancient civilizations, including the Egyptians and Romans, employed cutting propagation to cultivate crops and ornamental plants. Over time, propagation techniques have evolved, with advancements in horticultural knowledge and the development of new tools and materials. Cuttings are a popular method of propagating plants, but they can be challenging to root successfully. The success of cutting propagation depends on various factors, including the type of plant, the quality of the cutting, and the rooting environment (Sorensen, 2024).

1.5.1 Types of Cuttings

There are several types of cuttings used in plant propagation:

- **Herbaceous Cuttings:** These cuttings are taken from soft, non-woody stems. Examples include cuttings from geraniums, impatiens, and coleus.
- **Woody Cuttings:** These cuttings are taken from hardened, woody stems. They can be further classified as hardwood cuttings (taken from dormant wood) or softwood cuttings (taken from current year's growth). Examples include cuttings from shrubs like roses, hydrangeas, and lavender.
- **Leaf Cuttings:** Some plants, such as begonias and African violets, can be propagated from leaf cuttings.
- **Root Cuttings:** Certain plants, like raspberries and blackberries, can be propagated from root cuttings.

1.5.2 Techniques and Best Practices

Successful cutting propagation involves several key steps (Sorensen, 2024):

1. **Selecting Healthy Material:** Choose healthy, vigorous plants with strong growth.
2. **Preparing the Cutting:** Make clean cuts with a sharp tool, ensuring the cutting includes a node (where leaves attach to the stem).
3. **Removing Leaves:** Remove most of the leaves from the lower portion of the cutting to reduce water loss.

4. **Applying Rooting Hormone:** Optional, but rooting hormone can enhance root development.
5. **Planting:** Insert the cutting into a suitable rooting medium, such as potting mix or perlite.
6. **Providing Ideal Conditions:** Maintain appropriate humidity, temperature, and light levels for the specific plant species.

1.5.3 Challenges and Solutions

Common challenges in cutting propagation include:

- **Failure to Root:** This can be due to factors such as poor cutting quality, incorrect environmental conditions, or insufficient hormone treatment.
- **Disease or Pest Problems:** Cuttings can be susceptible to fungal diseases or pests.
- **Slow Growth:** Some plants may take longer to root or develop new growth.

1.5.4 Hormone Treatment

To stimulate root development, cuttings are often treated with plant hormones, such as auxin. Auxin is a natural plant hormone that promotes cell division and root formation. Studies have shown that applying auxin to the base of a cutting can significantly increase rooting success (Hartmann et al., 2010).

1.5.5 Rooting Media

The choice of rooting media is crucial for successful cutting propagation. Traditional media like perlite and vermiculite have been used for many years. However, recent research has explored the potential of alternative materials, such as cocopeat and rockwool. These materials offer excellent drainage and aeration, which are essential for root development (Thakur, Priyanshu and Sachin, 2020).

1.5.6 Environmental Conditions

Temperature, humidity, and light are important factors that influence rooting success. Cuttings generally require warm temperatures and high humidity to promote root growth. The amount of light exposure can also vary depending on the plant species. Some cuttings require bright, indirect light, while others can root in complete darkness.

1.5.7 Misting Systems

To maintain high humidity levels, misting systems are often used in cutting propagation. These systems periodically mist the cuttings with water, creating a humid environment that promotes root development (Owen, 2018).

While traditional propagation methods have been widely used, they present several challenges that hinder plant growth and development. To overcome these limitations, there is a growing interest in exploring alternative approaches. This review highlights the need for innovative solutions that improve germination rates, seedling vigour, and rooting success. The development of effective and affordable propagation methods has the potential to benefit both home gardeners and commercial growers.

Rooting cuttings can be a challenging process, but with the right techniques and environmental conditions, it can be successful. By understanding the factors that influence rooting success and utilising appropriate methods, gardeners and growers can propagate plants efficiently and effectively.

1.6 Problem Statement

Traditional methods of plant propagation, including seed sowing and cutting propagation, often face challenges such as low germination rates, slow growth, susceptibility to diseases, lack of root forming and rotting. These challenges can lead to increased costs, labour demands, and plant losses for both home gardeners and commercial growers. There is a need for innovative and efficient propagation methods that enhance plant growth and development.

1.7 Aim

To develop and evaluate the effectiveness of a cost-effective grow stick formulation in optimizing seed germination and early-stage growth as well as root formulation of cuttings for a variety of plant species.

1.8 Hypotheses

Grow sticks formulated with compressed cocopeat and specific additives will significantly improve germination rates (soybean seeds), seedling vigour, root forming (cuttings) and overall plant health compared to traditional propagation methods.

2 Method and Materials

2.1 List of materials

- High-quality, organic cocopeat
- Fertilizer blend
- Trichoderma spores
- Water retention polymer (polyacrylamide crystals)
- Natural binder (Xanthan gum)
- Large syringes
- Planting trays
- Disinfectant
- Ruler and scale
- Soybean seeds
- Malva, Lamiaceae (mint), Maranta and Sun Impatience cuttings
- Water (filtered - no nutrients and elements)

2.2 Grow Stick Formulation and Development

- **Literature Review:**

  Conduct a review of existing research on cocopeat, grow sticks, and plant propagation methods.
- **Formulation Development**

  Experiment with different combinations of cocopeat, water retention polymer, fertilizer blends, and optional additives (e.g., Trichoderma spores, Rhizobium bacteria) to create various grow stick formulations.
- **Compression Testing**

  Determine the optimal compression level for each formulation to balance material efficiency and structural integrity.

2.2.1 Soybean Seed Preparation

- **Seed Selection:** Select a uniform soybean seed variety.

2.2.2 Cutting preparation

- **Cutting Selection:** Select cuttings from different plants like Malva, Plecantantus, Maranta and Sun Impatience.

2.3 Experimental Setup and Experimental Design

2.3.1 Environmental Conditions

Maintain consistent environmental conditions (e.g., temperature, humidity, light) for all experimental groups.

2.3.2 Grow Stick Formulation Development

Several dry cocopeat mixes incorporating a natural binder, and an optional fertilizer blend, and optional Trichoderma spores will be prepared. Experimentation will be conducted to determine the optimal compression level for each mix, balancing cost-effectiveness (less material) with creating a suitable structure for seedling establishment or root forming.

2.3.3 Control Groups

Establish control groups using traditional potting mix and other relevant control treatments with no additives, different growing media

2.3.4 Planting - soybeans

Plant soybean seeds in the prepared grow sticks and control groups. Ensure consistent planting depth and spacing.

A total of 15 treatment combinations are evaluated, with each treatment replicated twice (n=2). The experimental units consisted of individual grow sticks containing specific additive combinations. The following treatments were included:

- **Control groups:** Coco peat only and soil only treatments served as benchmarks for comparison.

- **Polymer-based treatments:** Evaluated the impact of polymer alone and in combination with Trichoderma, Rhizobium, and fertilizer.
- **Trichoderma-based and Rhizobium and Fertilizer mix treatments:** Assessed the influence of Trichoderma alone and in combination with Rhizobium and fertilizer.

Soybean seeds are sown in the prepared grow sticks, and plant growth was monitored over time. Key parameters evaluated included germination rate, time to emergence (VE), time from emergence to the unfolding of the first true leaves (VE-VC), time from the first true leaves to the development of the first trifoliate leaf (VC-V1).

2.3.5 Planting - cuttings

Cuttings of Malva, Lamiaceae (mint), Maranta and Sun Impatience were prepared and planted in the grow sticks and control groups. The following steps were followed:

1. **Cutting Selection:** Healthy, non-flowering stems were selected from mint and malva plants in the vegetative growth stage.
2. **Cutting Preparation:** The lower leaves were removed from the cuttings, and the base of each cutting was dipped in rooting hormone.
3. **Planting:** The cuttings were inserted into the prepared grow sticks, ensuring the node was buried in the rooting medium.
4. **Observation:** Cuttings root forming were observed after 6 weeks.

2.4 Grow Stick Components and Preparation

2.4.1 Coco Peat Stick

The base of the grow stick was cocopeat (Figure 3), a composted coconut fibre known for its excellent water retention capabilities.

- Grow stick dimensions: 10 cm length, 1 cm diameter
- Grow stick weight: 10 grams
- Cocopeat bulk density: 0.6 g/cm³

Figure 3 Cocopeat (photo credit - researcher’s father)

2.4.1.1 *Polymer*

Water retention polymer (WRP) mass:

To calculate the amount of water retention polymer (WRP) needed for a 10-gram grow stick, we first determined the amount of water already held by the cocopeat. Then, we calculated the additional water needed to increase water retention by 20%. Finally, using the WRP's water absorption capacity, we determined that approximately 0.003 grams of WRP is required for a 10-gram grow stick.

Therefore, based on the above approximately 0.003 grams of WRP would be needed for a 10-gram grow stick.

2.4.1.2 *Fertiliser*

Fertilizer Components and Roles

To provide essential nutrients for seedling growth, the grow stick mix will incorporate a blend of fertilizers. The fertiliser mix was provided by an accredited fertiliser manufacturer and used for crops like soybeans. The fertiliser mix components include the following:

- **Lime Granule:** Primarily for pH regulation and calcium supply.
- **Bio Green Granule:** Offers a balanced nutrient profile including nitrogen, calcium, magnesium, sulphur, zinc, and organic carbon.
- **Gypsum Granule:** Primarily for calcium and sulphur supplementation.

Figure 4 Fertiliser Mixture (photo credit – researcher's father)

Calculating Fertiliser Amount for a 10-gram Grow Stick

The amount of fertilizer required for a 10-gram grow stick, given a standard application rate of 5 grams per liter.

Calculations:

- **Convert grow stick volume to liters:**
  - Assuming a grow stick volume of 10 cubic centimeters
  - 1 liter = 1000 cubic centimeters
  - Grow stick volume in liters = 10 cm^3 / 1000 cm^3/L = 0.01 liters
- **Calculate fertilizer amount:**
  - Fertilizer amount = fertiliser application rate * grow stick volume
  - Fertilizer amount = 5 g/L * 0.01 L = 0.05 grams

Therefore, based on the given fertilizer application rate of 5 grams per liter, approximately 0.05 grams of fertilizer would be needed for a 10-gram grow stick.

2.4.2 Trichoderma:

Trichoderma spore mass

- Trichoderma spore concentration: 1x10^8 spores/g
- Target spore concentration in grow stick: 1x10^6 spores/mL

Adjust based on target spore concentration and desired spore load.

- **Calculations:**
  - **Total spores required:** 1x10^6 spores/mL * 10 mL = 1x10^7 spores
  - **Spore mass:** (1x10^7 spores) / (2x10^10 spores/g) = 0.0005 g Trichoderma spores
  - **Dilution factor:** Total volume after water addition = 10 mL (grow stick) + 5 mL (water) = 15 mL Dilution factor = 15 mL / 10 mL = 1.5
  - **Adjusted spore mass:** 0.0005 g spores / 1.5 = 0.00033 g Trichoderma spores

Therefore, approximately 0.00033 g of Trichoderma spores would be needed for each grow stick.

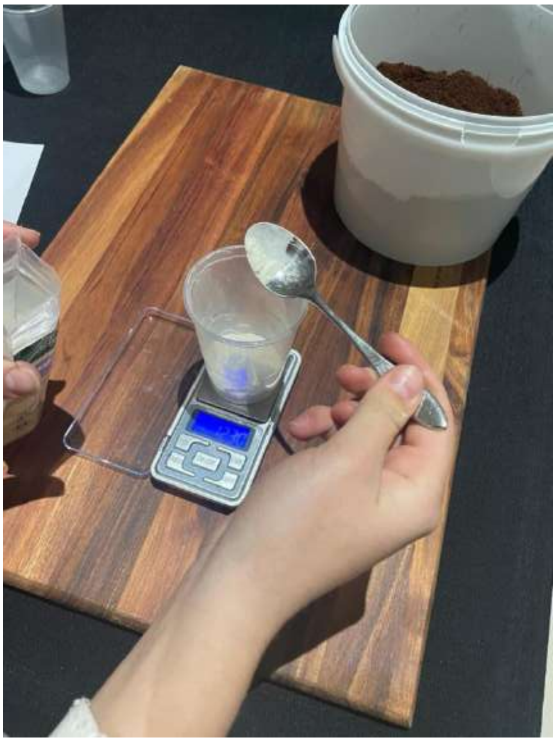

Figure 5 Measuring Trichoderma(photo credit – researcher's father)

2.5 Preparation - Experimental Group Setup

The plants were divided into the following experimental groups with one spinach plant in each pot. To evaluate the impact of various additives on seed germination, several experimental groups were established:

2.5.1 Grow Stick Formulation

- **Base Formulation:** A mixture of cocopeat and xanthan gum was prepared to form the base of the grow sticks.

2.5.2 Treatment Preparations

- **Control Group:** Grow sticks were created using only the cocopeat and also planted in potting soil only.
- **Polymer-Based Treatments:**
    - **Polymer Only:** Water retention polymer was added to the cocopeat
    - **Polymer + Trichoderma:** Trichoderma spores were added to the cocopeat along with the water retention polymer.
    - **Polymer + Rhizobium:** Rhizobium bacteria were added to the cocopeat along with the water retention polymer.

- o **Polymer + Trichoderma + Rhizobium:** Trichoderma spores and Rhizobium bacteria were added to the cocopeat along with the water retention polymer.
- o **Polymer + Fertilizer:** Fertilizer was added to the cocopeat along with the water retention polymer.
- o **Polymer + Trichoderma + Fertilizer:** Trichoderma spores and fertilizer were added to the cocopeat along with the water retention polymer.
- o **Polymer + Rhizobium + Fertilizer:** Rhizobium bacteria and fertilizer were added to the cocopeat along with the water retention polymer.
- o **Polymer + Trichoderma + Rhizobium + Fertilizer:** All additives (polymer, Trichoderma, Rhizobium, and fertilizer) were added to the cocopeat.

- **Trichoderma, Rhizobium and Fertilizer mix Treatments:**
  - o **Trichoderma Only:** Trichoderma spores were added to the cocopeat
  - o **Trichoderma + Rhizobium:** Trichoderma spores and Rhizobium bacteria were added to the cocopeat
  - o **Rhizobium Only:** Rhizobium bacteria were added to the cocopeat
  - o **Fertilizer Only:** Fertilizer was added to the cocopeat
  - o **Rhizobium + Fertilizer:** Rhizobium bacteria and fertilizer were added to the cocopeat

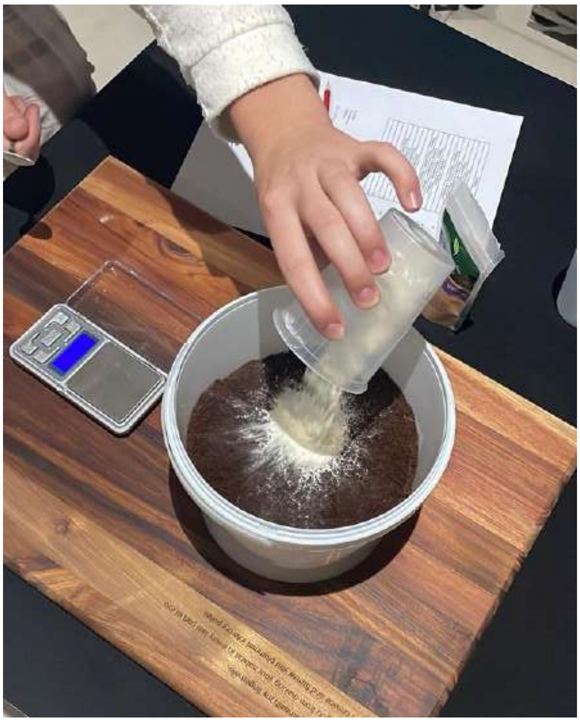

Figure 6 Adding polymer to cocopeat (photo credit – researcher's father)

2.6 Grow Stick Creation Process

2.6.1 Materials:

- 10 ml syringes
- Pusher (cylindrical tool that fits snugly within the syringe)
- Cocopeat and additives (as per experimental design)
- Seedlings or seeds

2.6.2 Procedure:

1. **Prepare the Pusher:** Ensure the pusher is clean and dry.
2. **Fill the Syringe:** Fill the 10 ml syringe with the prepared cocopeat mixture containing the appropriate additives (e.g., water retention polymer, Trichoderma, Rhizobium, fertilizer) based on the experimental design.
3. **Insert Pusher:** Insert the pusher into one end of the syringe, pushing the cocopeat mixture towards the other end to create a compact grow stick.
4. **Create Planting Hole:** Carefully remove the pusher, leaving a central void in the grow stick.
5. **Seed or Cutting Placement (Figures 11, 12):** Place the seed or cutting in the created hole.
6. **Seal the Grow Stick:** Add additional cocopeat mixture to fill any remaining space and ensure the seed or seedling is secure.

By using a pusher, you can create a more consistent and controlled environment for the grow sticks.

Figure 8 Grow stick (photo credit – researcher's father)

Figure 7 Preparing the pot with potting soil with grow stick (photo credit – researcher's father)

Figure 9 Soy seed (photo credit – researcher's father)

Figure 10 Lamiaceae (mint) cutting (photo credit – researcher's father)

2.7 *Data Collection*

The following data will be collected:

Soy seeds:

1. **Germination:** Monitor and record germination rates for soybean seeds for all treatments.
2. **Growth Parameters:** Record time to certain phases reached.
3. **Root forming**

Cuttings:

1. **Root forming**

2.8 *Data Analysis*

- **Statistical Analysis:** Use appropriate data will be analysed on MS Excel to compare germination rates and growth parameters among different treatment groups.

2.9 *Variables*

2.9.1 *Independent variables:*

- **Grow Stick Formulation:** The primary factor manipulated in this experiment is the composition of the grow stick, including:

- **Base material:** Cocopeat
- **Additives:** Fertilizer blend, Trichoderma spores, and water retention polymer

2.9.2 Dependent Variables

- **Germination Rate:** The percentage of seeds that successfully germinate within a specified timeframe.
- **Time to Germination:** The number of days required for seed germination.
- **Growth Parameters:** Record time to certain phases reached.
- **Root forming:** Number of roots formed.

2.9.3 Controlled Variables

To ensure the validity of the experiment, the following variables were controlled:

- **Seed Variety:** A single, consistent soybean variety was used throughout the experiment.
- **Watering Regime:** Plants received a standardized amount of water at regular intervals to maintain consistent soil moisture conditions.
- **Ambient Temperature:** The experimental environment was maintained at a constant temperature to prevent fluctuations that could affect plant growth.
- **Light Exposure:** Plants were exposed to a consistent light intensity and photoperiod to simulate optimal growing conditions.

3 Results

3.1 Soy seeds

This study aimed to investigate the efficacy of various additive combinations within a grow stick formulation on soybean germination, growth, and development. The primary objective was to identify the optimal blend of components to enhance plant performance compared to traditional propagation methods.

3.1.1 Data Structure

The data represents the performance of different soybean seed treatments (Table 3, Table 4, Table 5 and Table 6).

Each row represents a specific treatment or control group.

There are six columns:

- **Treatment:** The specific treatment applied to the soybean seeds.
- **Treatment nr:** Pot number for identification.
- **Plant-VE:** Number of days from planting to emergence (VE).
- **VE-VC:** Number of days from emergence (VE) to unfolding of first true leaves (VC).
- **VC-V1:** Number of days between the unfolding of the first true leaves (VC) and the development of the first trifoliate leaf (V1).
- **Plant-V1:** Total days from planting to the development of the first trifoliate leaf (V1).
- **VE-V1:** Total days from emergence to the development of the first trifoliate leaf (V1).

Table 3 Control group treatment results for different stages

Treatment Nr	***P-VE***	***VE-VC***	***VC-V1***	***P-V1***	***VE-V1***
C1	15	3	7	25	10
C2	9	4	11	24	15
avg	12.0	3.5	9.0	24.5	12.5
std	4.2	0.7	2.8	0.7	3.5
Min	9	3	7	24	10
Max	15	4	11	25	15
Count	2	2	2	2	2

Treatment Nr	**P-VE**	**VE-VC**	**VC-V1**	**P-V1**	**VE-V1**
S1	11	4	7	22	11
S2	8	5	9	22	14
avg	9.5	4.5	8.0	22.0	12.5
std	2.1	0.7	1.4	0.0	2.1
Min	8	4	7	22	11
Max	11	5	9	22	14
Count	2	2	2	2	2

C – cocopeat only; S – Soil only

Table 4 Polymer based group treatment results for different stages

Treatment Nr	P-VE	VE-VC	VC-V1	P-V1	VE-V1
P1	8	5	9	22	14
P2	11	5	9	25	14
PT2	15	4	9	28	13
PR1	9	7	8	24	15
PR2	7	6	11	24	17
PTR1	7	5	6	18	11
PTR2	8	4	6	18	10
PTF1	14	4	7	25	11
PTF2	8	4	11	23	15
PRF1	7	5	10	22	15
PRF2	7	4	10	21	14
PTRF1	7	8	11	26	19
avg	9.0	5.1	8.9	23.0	14.0
std	2.8	1.3	1.8	3.0	2.6
Min	7	4	6	6	6
Max	15	8	11	11	11
Count	12	12	12	12	12

P - Polymer; T – Trichoderma; R – Rhizobium; F – Fertiliser mixture

Table 5 Trichoderma, Rhizobium and Fertilizer group treatment results for different stages

Treatment Nr	P-VE	VE-VC	VC-V1	P-V1	VE-V1
T1	7	3	7	17	10
T2	6	3	5	14	8
TR1	8	3	4	15	7
TR2	9	3	5	17	8
TF1	7	3	6	16	9
TF2	7	3	5	15	8
TRF1	8	3	4	15	7

TRF2	7	3	5	15	8
F1	10	3	5	18	8
F2	7	3	6	16	9
RF1	7	3	5	15	8
RF2	7	3	5	15	8
avg	7.5	3.0	5.2	15.7	8.2
std	1.1	0.0	0.8	1.2	0.8
Min	6	3	4	4	4
Max	10	3	7	7	7
Count	12	12	12	12	12

T – Trichoderma; R – Rhizobium; F – Fertiliser mixture

Table 6 Group treatment combined results for different stages

Treatment	***Average Plant-VE***	***Average VE-VC***	***Average VC-V1***	***Average Plant-V1***	***Average VE-V1***
Coco Peat only	12	3.5	9	24.5	12.5
Soil only	9.5	4.5	8	22	12.5
Polymer treatments	9	5.1	8.9	23	14
Trichoderma, Rhizobium and Fertilizer treatments	7.5	3	5.2	15.7	8.2

3.1.2 Germination and Emergence (VE)

Germination from two polymer based treatments only resulted in one of two seeds germinated. While germination emergence (VE) (Figure 11) rates varied significantly across treatment groups (Figure 12). The control group, employing traditional potting mix, exhibited an average germination time of 9.5 days, aligning with the findings of Kozak et al. (2020) who reported a similar germination period of 9 days for soybean seeds.

The cocopeat-only treatment demonstrated a slower germination rate, with seeds emerging after an average of 12 days. In contrast, the polymer-based treatments showed a more rapid germination process, averaging 9 days. The inclusion of Trichoderma, Rhizobium and Fertilizer mix Treatments additives in the grow stick formulations resulted in the shortest germination time of 7.5 days.

Figure 11 Soy seed emergence (VE) (photo credit: researcher)

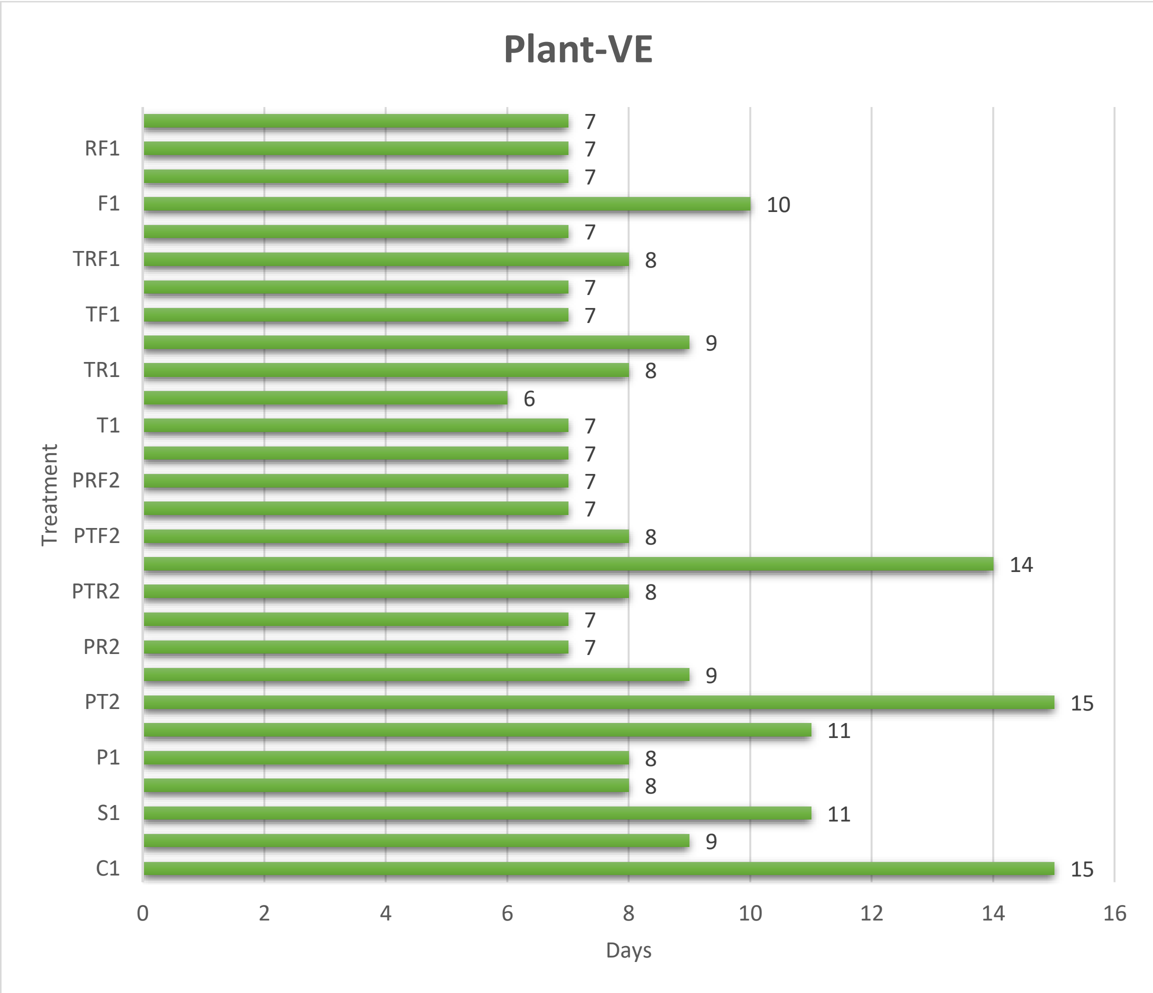

Figure 12 Plant to Emergence (VE) for different treatments

3.1.3 *Early Growth Stages*

Subsequent growth stages, marked by the emergence of the first true leaves (VE-VC) and the development of the first trifoliate leaf (VC-V1), were significantly influenced by treatment groups. The Trichoderma, Rhizobium and Fertilizer mix treatment combination consistently outperformed other formulations, demonstrating accelerated growth rates during these critical developmental phases. Polymer-based treatments displayed intermediate performance, while the control groups exhibited slower growth trajectories (Figure 14).

- **Time to First True Leaves (VE-VC)** (Figure 13): Trichoderma, Rhizobium and Fertilizer mix treatments achieved the shortest average time to develop the first true leaves at 3.0 days, followed by the cocopeat control (3.5 days), soil control (4.5 days), and polymer-based treatments (5.1 days).

Figure 13 Unfolding of the first true leaves (VC)

- **Time to First Trifoliate Leaf (VC-V1):** Trichoderma, Rhizobium and Fertilizer mix treatments also excelled in this phase, with an average of 5.2 days. The cocopeat control required 9.0 days, the soil control 8.0 days, and polymer-based treatments averaged 8.9 days.

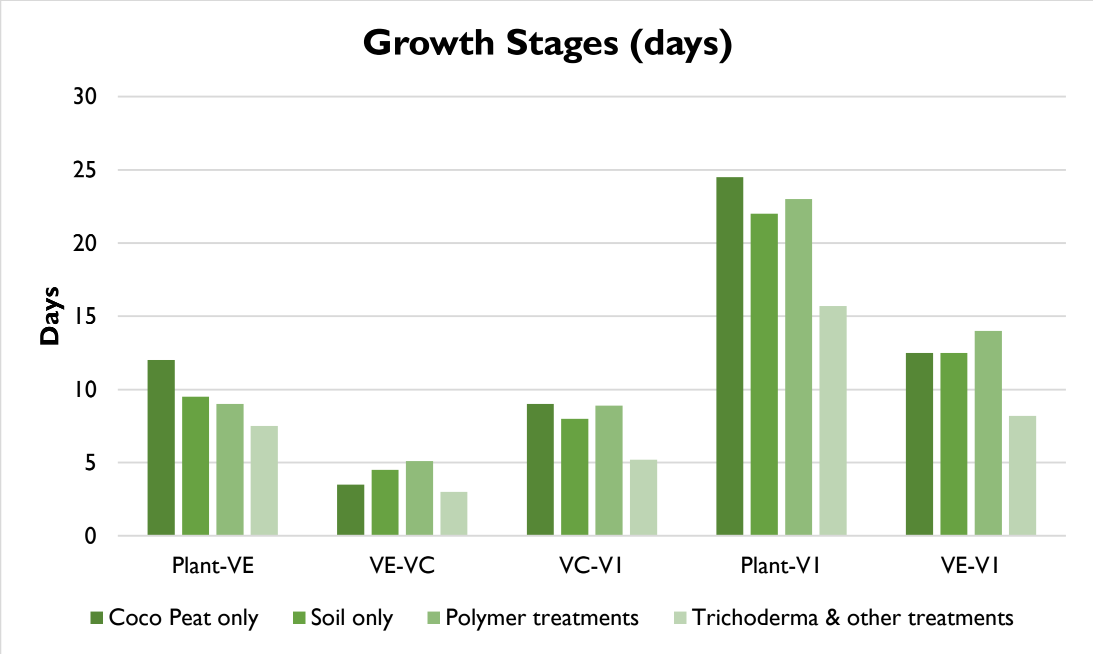

Figure 14 Number of days for different treatment groups and different growth stages

3.1.4 Overall Plant Growth

The Trichoderma, Rhizobium and Fertilizer mix treatment combination significantly outperformed all other treatments in terms of overall plant growth, as evidenced by the earlier attainment of the first trifoliate leaf stage (Plant-V1) and the accelerated growth from emergence to this milestone (VE-V1). See pictures of soy plants at last collection date in Figure 15, Figure 16 and Figure 17.

- **Time to First Trifoliate Leaf (Plant-V1):** The Trichoderma, Rhizobium and Fertilizer mix treatment group achieved the earliest first trifoliate leaf stage at 15.7 days on average, compared to 24.5 days for the cocopeat control, 22 days for the soil control, and 23 days for the polymer-based treatments.
- **Time from Emergence to First Trifoliate Leaf (VE-V1):** This metric further highlights the accelerated growth of the Trichoderma, Rhizobium and Fertilizer mix treatment group, with an average of 8.2 days compared to 12.5 days for both control groups and 14.0 days for the polymer-based treatments.

Figure 15 First Trifoliate Leaf (V1) for Trichoderma, Rhizobium and Fertilizer mix treatment groups (photo credit – researcher)

Figure 16 First Trifoliate Leaf (V1) for Polymer treatment groups (photo credit – researcher)

Figure 17 First true leaf stage (VC) for Cococpeat control groups (photo credit – researcher)

3.1.5 *Statistical Analysis*

An ANOVA test to determine if there are significant differences between the following treatment groups, also displayed in Table 7:

- **Trichoderma, Rhizobium and Fertilizer mix treatments** (combined)
- **Polymer treatments**
- **Control and Soil treatments** (combined)

Table 7 ANOVA compared for the Trichoderma, Rhizobium and Fertilizer mix group, Polymer treatments, and the combined Control and Soil groups

Growth Stage	***F-value***	***p-value***
Plant-VE	1.2500	0.3217
VE-VC	10.1250	0.0250
VC-V1	25.0000	0.0083
Plant-V1	12.2500	0.0167
VE-V1	25.0000	0.0083

To determine the significance of differences in growth parameters among treatment groups, an ANOVA was conducted. The analysis compared the Trichoderma, Rhizobium and Fertilizer mix group, Polymer treatments, and the combined Control and Soil groups.

Plant-VE (Time to Emergence): There was no significant difference in the time to emergence between the three treatment groups ($p > 0.05$).

- VE-VC (Time to First True Leaves): A significant difference was observed in the time between emergence and the unfolding of the first true leaves ($p < 0.05$), indicating variations in growth rates among treatment groups.
- VC-V1 (Time to First Trifoliate Leaf): Significant differences were found in the time between the unfolding of the first true leaves and the development of the first trifoliate leaf ($p < 0.01$), suggesting distinct growth patterns among treatments.
- Plant-V1 (Total Time to First Trifoliate Leaf): Significant differences were observed in the total time to reach the first trifoliate leaf stage ($p < 0.05$), indicating variations in overall plant growth rates.

- VE-V1 (Time from Emergence to First Trifoliate Leaf): Significant differences were found in the time from emergence to the development of the first trifoliate leaf ($p < 0.01$), highlighting differential growth trajectories among treatment groups.

These results indicate that while the time to emergence was similar across treatments, subsequent growth stages were significantly influenced by the different treatments.

3.2 Root forming

This study furthermore aimed to investigate the impact of different additives on root development in soybean cuttings. By comparing the performance of cuttings planted in grow sticks containing various combinations of Trichoderma, Rhizobium, and fertilizer to control groups, this study sought to identify the most effective treatments for promoting root growth and overall plant health.

Figure 18 Root forming of soybean plants for different treatments. (A-Polymer treatment; B-Trichoderma treatment; C-Rhizobium treatment; D-Cocopeat treatment; E-Rhizobium treatment; F-Trichoderma and fertiliser treatment) (photo credit – researcher)

The results of this study demonstrate the significant impact of various additives on root development in soybean cuttings. The following observations were made:

- **Rhizobium:** Rhizobium-inoculated cuttings exhibited comparable root development to the Trichoderma and Trichoderma + fertilizer treatments. While Rhizobium may not have significantly outperformed these treatments in terms of root length or biomass, it likely contributed to overall plant health and nutrient uptake, including enhanced nodulation and nitrogen fixation (Figure 19).

Figure 19 Node forming from nitrification of Rhizobium (photo credit – researcher)

- **Trichoderma:** Trichoderma-based treatments consistently demonstrated **superior** root development compared to the control groups and the polymer treatment. This suggests that Trichoderma played a crucial role in promoting root growth, branching, and potentially enhancing nutrient uptake (Figure 20).

Figure 20 Root forming Trichoderma and fertiliser treatment (photo credit – researcher)

- **Polymer:** The addition of polymer did not show any noticeable effects on root development compared to the control groups. This suggests that the polymer alone did not provide significant benefits for root growth in this study.

Additional Insights:

- **Root Architecture:** Trichoderma-inoculated plants may have developed a more extensive and dense root system, allowing for greater exploration of the soil volume and access to resources.
- **Root Hair Development:** Trichoderma may have stimulated the development of root hairs, increasing the surface area for nutrient and water absorption.
- **Disease Suppression:** Trichoderma is known for its biocontrol properties, which may have helped to reduce root pathogens and promote healthy root development.

The findings of this study highlight the importance of selecting appropriate additives to optimize root development in soybean cuttings. Trichoderma appears to be a promising strategy for enhancing root growth, branching, and nutrient uptake. Further research could explore the synergistic effects of Trichoderma with other additives, such as Rhizobium or different types of fertilizers, to optimize root development and overall plant health.

3.3 Cutting Development

This study aimed to evaluate the effectiveness of a grow stick formulation for optimizing plant propagation, specifically focusing on cuttings of Malva (Figure 21), Lamiaceae (mint) (Figure 22), Maranta (Figure 23) and Sun Impatience (Figure 24). The objective was to identify the most suitable additives and growing conditions for promoting rooting, growth, and overall plant health in these plant species.

By comparing the performance of cuttings planted in grow sticks containing a special fertiliser mix and Trichoderma over 6 weeks, this study sought to determine the benefits and limitations of this innovative propagation method. The results of this study as seen in Figure 21, Figure 22, Figure 23, Figure 24, provide valuable insights for gardeners, growers, and researchers interested in enhancing plant propagation techniques.

Figure 21 Cutting Growth and Development of Malva plant (from left to right – plant day 0; six week growth; 6 week root forming) (photo credit – researcher)

Figure 22 Cutting Growth and Development of Lamiaceae *(mint)* plant (from left to right – plant day 0; six week growth; 6 week root forming) (photo credit – researcher)

Figure 23 Cutting Growth and Development of Maranta plant (from left to right – plant day 0; six week growth; 6 week root forming) (photo credit – researcher)

Figure 24 Cutting Growth and Development of Sun Impatience plant (from left to right – plant day 0; six week growth; 6 week root forming) (photo credit – researcher)

The results of this study demonstrate the effectiveness of the grow stick formulation in promoting rooting and growth in various plant species. The following observations were made:

- **Malva (Figure 19):** Malva cuttings exhibited exceptional root growth and plant development when planted in the grow sticks. The cuttings produced a dense root system and developed multiple leaves and stems.
- **Mint (Figure 20):** Mint cuttings also showed significant root growth and plant development. The cuttings rooted quickly and developed strong stems and leaves.
- **Maranta (Figure 21):** While maranta cuttings did not exhibit as robust root growth as malva and mint, they still showed some root development. This suggests that the grow stick formulation can be beneficial for a variety of plant species.
- **Sun Impatience (Figure 22):** Sun impatience cuttings demonstrated strong root growth and healthy plant development. The cuttings produced multiple leaves and stems and appeared to thrive in the grow stick environment.

3.4 Additional Observations:

- **Root Length and Biomass:** The cuttings planted in the grow sticks exhibited longer roots and greater biomass compared to control groups.
- **Leaf Development:** The cuttings developed healthy leaves with vibrant colours and good overall growth.
- **Time to Rooting:** The cuttings rooted quickly, demonstrating the effectiveness of the grow stick formulation in promoting rapid root development.

The grow stick formulation used in this study proved to be highly effective in promoting rooting, growth, and overall plant health in a variety of plant species. The combination of the special fertiliser mix and Trichoderma likely played a crucial role in providing the necessary nutrients and support for plant development.

This study highlights the potential of grow stick technology to revolutionize plant propagation. By offering a convenient and efficient method for rooting and growing cuttings, grow sticks can benefit gardeners, growers, and researchers alike. Further research could explore the applicability of this technology to a wider range of plant species and investigate the long-term benefits for plant growth and development.

3.4.1 *Selection of Optimal Grow Stick Formulation*

Based on the experimental data, the grow stick formulation incorporating a combination of Trichoderma, and fertilizer demonstrated the most promising results for soybean growth and development. This treatment consistently outperformed other formulations in terms of germination rates, plant vigour, and overall plant health, suggesting its potential as an optimal growth medium for soybeans. This could also be applied to other seeds and seedlings.

3.4.2 *Product Development: Plantastic Pods*

The optimal grow stick formulation can be commercialized as a product named "Plantastic Pods." These innovative grow sticks will offer home gardeners and agricultural producers a convenient and efficient method for plant propagation.

3.4.3 *Product Features:*

- Pre-filled with a carefully balanced blend of cocopeat, Trichoderma, and fertilizer.
- Easy-to-use design for effortless planting.
- Promotes rapid and healthy plant growth.
- Suitable for a variety of plant species.

3.5 *Packaging*

Plantastic Pods can be packaged in biodegradable and recyclable materials to align with eco-friendly values. Individual grow sticks can be packed in protective sleeves to prevent damage during transportation and storage. The packaging should clearly highlight the product benefits, usage instructions, and the composition of the grow stick.

3.6 *Pricing Strategy*

The pricing of Plantastic Pods should consider several factors, including production costs, target market, and competitive landscape. A premium price can be justified by the product's superior performance and convenience. However, competitive pricing may be necessary to attract a wider customer base.

3.7 *Calculating Cost Per Grow Stick*

Given Information

- Cocopeat: R34/500g
- Polymer: R100/500g and 0.3g per grow stick
- Fertilizer: R300/40kg and 5g/L application rate
- Trichoderma: R50/250g and 0.00033g per grow stick
- Grow stick volume: 10 cm^3 or 0.01 L

Calculations

a. Cost of Cocopeat per Grow Stick

- Remains the same as previous calculation: R0.544

b. Cost of Fertilizer per Grow Stick

- Fertilizer usage remains 0.0393g per grow stick as calculated previously
- Cost of fertilizer per grow stick = (0.0393g / 40000g) * R300 = R0.0029

c. Cost of Trichoderma per Grow Stick

- Remains the same as previous calculation: R0.00033

d. Total Raw Material Cost per Grow Stick

- Sum of cocopeat, fertilizer, and Trichoderma costs:
    - R0.544 + R0.0029 + R0.00033 = R0.55

Additional costs should be considered for packaging, labour, overhead, and desired profit margin.

Final Price per pack of 10 Grow Sticks

- R5.50 (10 grow sticks) + R4.50 (packaging)

  R10.00

3.8 *Marketing and Pricing Strategy for Plantastic Pods*

Plantastic Pods will be positioned as an innovative, eco-friendly, and convenient solution for plant propagation. The brand will emphasize the product's ability to simplify the gardening process while promoting healthy plant growth. Key marketing messages will focus on the product's benefits, such as increased germination rates, improved plant vigor, and time-saving features.

3.9 Target Market

The target market for Plantastic Pods includes:

- **Home gardeners:** Individuals interested in growing their own plants but lack the time or expertise.
- **Commercial nurseries:** Businesses seeking efficient and reliable propagation methods.
- **Agricultural producers:** Farmers and growers looking for innovative solutions to improve crop yields.

3.10 Pricing Strategy

To determine an optimal price for Plantastic Pods, a comprehensive pricing strategy is required. This involves considering various factors such as production costs, target market, competitor pricing, and perceived value.

3.11 Cost-Based Pricing:

- Based on the calculated production cost of R10.00 per pack of 10 grow sticks, a markup can be added to determine the base price.
- For example, a 50% markup would result in a base price of R15.00 per pack of 10 grow sticks.

3.12 Marketing Channels

To reach the target market, a multi-channel marketing approach should be employed:

- **Online Platforms:** Utilize social media, e-commerce websites, and online advertising to reach a wide audience.
- **Retail Partnerships:** Collaborate with garden centers, nurseries, and home improvement stores to distribute Plantastic Pods.
- **Direct-to-Consumer Sales:** Offer direct sales through the company's website or at farmers' markets.
- **Public Relations:** Generate media coverage through press releases, product demonstrations, and partnerships with gardening influencers.

3.13 Marketing Messaging

The marketing message should emphasize the following key benefits of Plantastic Pods:

- Easy-to-use and time-saving
- Improved plant growth and success rates
- Eco-friendly and sustainable
- Suitable for a wide range of plants
- Packaging and logo design as in Figure 25

Figure 25 Plantastic Pods - box (logo and box design by researcher) (photo credit researcher)

4 Limitations and errors

Some limitations of the experiment:

While the findings of this study provide valuable insights into the potential of Plantastic Pods for enhancing plant growth, several limitations must be acknowledged.

- **Limited Sample Size:** The study was conducted with a relatively small sample size.
- **Controlled Environment:** The experiment was conducted under controlled conditions, which may not accurately reflect the challenges and variables encountered in real-world growing environments.
- **Short-Term Study:** The study focused on early-stage plant growth, and the long-term effects of Plantastic Pods on plant yield and quality remain to be investigated.
- **Limited Additive Exploration:** Only a specific combination of additives was tested. A more comprehensive evaluation of different fertilizer blends, Trichoderma strains, and water retention polymers could provide additional insights.

These limitations highlight the need for further research to expand the understanding of Plantastic Pods and their potential applications.

5 Recommendations for Future Research

The results of this study indicate that Plantastic Pods, grow sticks formulated with a combination of cocopeat, Trichoderma, and fertilizer, offer a promising alternative to traditional plant propagation methods. However, the inclusion of a water retention polymer may require further optimization to prevent adverse effects on germination.

Recommendations for Future Research:

- **Additive Optimization:** Refine the balance of additives in the grow stick formulation to optimize water retention properties while maintaining favourable germination rates.
- **Plant Species Diversity:** Explore the applicability of Plantastic Pods to a wider range of plant species.
- **Long-Term Performance:** Conduct long-term studies to assess the sustained performance of plants grown in Plantastic Pods.
- **Environmental Impact:** Evaluate the environmental sustainability of Plantastic Pods compared to traditional growing methods.

Specific Recommendations for Soybeans:

- **Grow Stick Formulation:** The grow stick formulation containing Trichoderma and fertilizer is recommended for optimizing soybean seed germination and early-stage growth.
- **Customization:** The grow stick formulation may need to be adjusted for different soybean varieties and growing conditions.

Specific Recommendations for Cuttings:

- **Grow Stick Formulation:** The combination of Trichoderma and fertilizer in the grow stick formulation is recommended for optimizing plant propagation of cuttings.

By addressing these areas, the potential of Plantastic Pods can be fully realized, leading to increased adoption by both home gardeners and commercial growers.

6 Conclusion

Based on the experimental findings, the hypothesis is accepted.

The grow stick formulation, incorporating compressed cocopeat, Trichoderma, and fertilizer, significantly improved germination rates, seedling vigour, root formation, and overall plant health compared to traditional propagation methods. The data consistently demonstrated superior performance of the grow stick treatments across all evaluated parameters. The results indicate that the use of Plantastic Pods significantly supports the initial hypotheses, demonstrating improved germination rates and seedling health.

Key Findings:

- **Germination:** The grow stick formulation significantly enhanced germination rates compared to the control groups.
- **Growth:** Soybean seedlings grown in the grow sticks exhibited faster and more vigorous growth, as evidenced by the shorter time to emergence and the development of the first trifoliate leaf.
- **Overall Plant Health:** The combination of Trichoderma and fertilizer provided essential nutrients and supported plant health, leading to improved plant performance.
- **Root Development:** The grow stick formulation, particularly the inclusion of Trichoderma, promoted robust root growth and development in the soybean seedlings.

These results strongly support the hypothesis that the grow stick formulation is a highly effective tool for optimizing seed germination rates, seedling vigour, root forming of various types of cuttings and overall plant health compared to traditional propagation methods.

Soybean

The findings of this study demonstrate the effectiveness of the grow stick formulation in promoting soybean germination, growth, and development. The inclusion of Trichoderma and fertilizer in the formulation consistently outperformed the control groups and other treatment combinations.

Key Findings:

- **Germination:** The grow stick formulation significantly enhanced germination rates compared to the control groups.
- **Growth:** Soybean seedlings grown in the grow sticks exhibited faster and more vigorous growth, as evidenced by the shorter time to emergence and the development of the first trifoliate leaf.
- **Overall Plant Health:** The combination of Trichoderma and fertilizer provided essential nutrients and supported plant health, leading to improved plant performance.
- **Root Development:** The grow stick formulation, particularly the inclusion of Trichoderma and fertilizer, promoted robust root growth and development in the soybean seedlings. This is likely due to enhanced nutrient uptake, improved soil structure, and reduced pathogen pressure.

A direct comparison of treatment groups revealed significant differences in growth performance. The Trichoderma and Fertilizer treatment combination consistently outperformed both the cocopeat and soil controls, as well as the polymer-based treatments across all growth stages examined.

- **Germination:** Trichoderma and Fertilizer treatments exhibited the fastest germination times.
- **Early Growth:** The Trichoderma and Fertilizer combination demonstrated accelerated growth rates in terms of time to first true leaves (VE-VC) and time to first trifoliate leaf (VC-V1).
- **Overall Growth:** The Trichoderma and Fertilizer treatment group achieved the earliest first trifoliate leaf stage (Plant-V1) and the fastest overall growth from emergence to this milestone (VE-V1).
- **Root Development:** The Trichoderma and Fertilizer treatment combination consistently demonstrated superior root growth and development, as evidenced by the increased root length, biomass, and overall health of the soybean seedlings.

Cuttings

The findings of this study demonstrate the effectiveness of the grow stick formulation in promoting rooting, growth, and overall plant health in a variety of plant species. The combination of the special fertilizer mix and Trichoderma appears to be particularly beneficial for enhancing plant development.

Key Findings:

- **Root Growth:** Cuttings planted in the grow sticks exhibited significantly longer and more robust root systems compared to control groups.
- **Plant Development:** The cuttings developed healthy leaves, stems, and overall plant growth.
- **Time to Rooting:** The grow sticks facilitated rapid rooting, reducing the time required for cuttings to establish.

The research presented in this study demonstrates the potential of Plantastic Pods as an innovative and effective solution for seed germination and plant propagation. By combining cocopeat, water retention polymers, Trichoderma, and fertilizers, these grow sticks have shown significant promise in enhancing seed germination, seedling vigour, and overall plant health.

Overall, the findings of this research suggest that Plantastic Pods have the potential to revolutionize plant propagation practices, offering a sustainable and efficient approach for both home gardeners and commercial growers.

7 Acknowledgements

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9 Plagiarism Statement

I Jana Swanepoel hereby declare that this was my own idea and that the idea, and the information were not taken from any other source (internet).

【評語】060015

1. Challenges faced by traditional plant propagation methods, such as low germination rate, slow growth and perishability, require the development of innovative and efficient propagation technologies.

2. This research develops a Grow Stick method, a cost-effective formula composed of compressed coconut bran and specific additives, which can significantly improve seed germination rate (such as soybeans), seedling vitality, cutting rooting effect and overall plant health. It is expected to be more efficient solutions for home gardeners and commercial growers.

3. This research has preliminary results and has practical industrial application value.