FINAL DESIGN REPORT

Optimizing Soilless Substrates and Germination Pods with Typha Fiber

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EXECUTIVE SUMMARY

This report presents the development of a peat-free seed germination pod utilizing Typha-based soilless media. In collaboration with Typha Co., the project builds on prior research done by the 2024 Typha capstone team on optimizing Typha-based growing media. The objective of this project is to provide a sustainable alternative to peat-based seed germinations pods within the commercial floriculture industry.

The project focused on improving the Typha-based media by incorporating soil amendments including perlite, pine fibre, and biochar. A six-week growth trial of petunia seedlings was conducted in a hydroponic wall system to assess the impact of these amendments on plant growth. Twelve different compositions of amended Typha-based media were tested against conventional growth substrates. Additionally, 11 technical specifications were identified to evaluate how the chemical and physical properties of amended Typha-based media compare to those of peat. Primary technical specifications include water holding capacity, nitrogen immobilization, and pH. The research also investigated the feasibility of forming Typha-based media into seed germination pods by application of a binding agent. Agar, yucca powder, molasses, and flaxseed mucilage were tested as binding agents during seed pod design. Binder performance was evaluated by structural integrity, impact resistance, and rehydration properties of the seed pod to ensure durability during transportation and usability in greenhouse settings.

Growth trials showed that [redacted] Further testing for the manufacturing process is recommended.

By leveraging Typha's nutrient retention and release properties, this project provides a sustainable media alternative for floriculture consumers, while also contributing to the ecological restoration of Lake Winnipeg. The development of a cost-effective solution has the potential for wide-scale adoption, reducing reliance on peat and its environmental impact. This approach aligns with the growing demand for sustainable agricultural practices, offering both environmental and economic benefits.

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GLOSSARY

Terms	Definitions
Water Holding Capacity	Represents the soil's ability to hold water against gravity, due to cohesive forces [1].
Nitrogen Immobilization	Occurs when microbes in soil use nitrate and ammonium found in soil for biological processes. This reduces the amount of available nitrogen in the soil for plant-use [2].
pH	Influences the availability of nutrients required for plant growth. A lower pH can make certain nutrients more readily available, the same can be said for a more basic pH. Balancing the pH for the preferred nutrient presence will affect plant development.
Electrical Conductivity	Measures the ability to carry an electrical charge.
Soil Respiration	Involves the release of carbon dioxide from the soil into the atmosphere due to biological processes, such as decomposition [3].
Bulk Density	Represents the dry mass over unit volume.
Total Porosity	Refers to the space between media particles which can be taken up by air and/or water.
Air-Filled Porosity	Corresponds to the available amount of pores in a medium for air to occupy, it is included in the total porosity.
Carbon-to-Nitrogen Ratio (C:N)	Represents the relative difference between the carbon and nitrogen found in soil.
Cation Exchange Capacity	Considers the capacity of soil to hold and exchange cations. It can help determine the soil's fertility [4].
Phytotoxicity	Measures the potential inhibition of plant growth due to the presence of certain chemicals.
Maximum Diameter	Measures the top circular width of the seed pods.
Height	Measures the depth of soilless media for the seed pods.

1 INTRODUCTION

Building on the success of the 2024 capstone project for developing a Typha-based growing medium, Typha Co. has launched this current research to refine the medium for use as a soilless germination pod. The following sections outline key information related to the development of this product.

1.1 Background Information

This project was initiated by Typha Co. in alignment with their interest towards advancing the sustainability of plant cultivation using Typha-based materials and hydroponic systems. Below is a summary of the key factors surrounding the development of the soilless media and germination pods.

1.1.1 Sustainability Concerns of Growing Mediums

Horticulture, defined as the cultivation of plants, has been recognized as a major contributor to global greenhouse gas emissions and environmental degradation by international commitments like the Paris Agreement [5] and United Nations Sustainable Development Goals [6]. Cultivators have begun reducing their reliance on non-renewable resources for plant growth and implementing sustainable alternatives to accomplish the same tasks. One material central to this conversation is peat moss, a common component in potting soil prized for its ideal plant-growing properties [7] but widely criticized for its energy-intensive and polluting harvest [8]. Therefore, the interest in developing peat-reduced and peat-free substrates is both relevant to horticulture and necessary in the fight against the climate crisis.

1.1.2 Soilless Growing Media

The use of soilless culture systems, referring to the cultivation of plants in substrates without soil [9], has already been implemented across many countries for the purpose of food production [10]. Floriculture, referring to the ornamental branch of horticulture, has also seen success with soilless farming [11] and the already fast-growing market is expected to accelerate as the industry shifts toward sustainable production practices [12]. The quality of the growing media directly contributes to the outcome of greenhouse growth [13], making it crucial that a high-quality, peat-free planting alternative is found.

1.1.3 Use of Typha in Soilless Growing Media

Cattails, known scientifically as Typha, are a genus of flowering aquatic and semi-aquatic marsh plants that are widely recognized features in wetlands, as shown in Figure 1. Typha has been used as an alternative and sustainable material for many applications ranging from packaging, textile fiber, insulation media, acoustic sound absorber, and biofuel [14]. While the plant is primarily used experimentally, its adaptability has created momentum to be explored in further applications. Its benefits to the environment, low carbon footprint, and high yield compared to other plant fibers [15] all exemplify why the cattail has been attributed the title of "miracle plant" [16]. Each cattail plant consists of several different parts, including the roots, leaves, stalk, and flower.

Figure 1. Cattail (Typha) plant [16].

Previous studies have explored the use of Typha as a substitute for peat [17], [18]. Typha Co., a biotechnology company that develops horticulture growing supplies using Typha-derived materials from the plants leaves and stalk, currently offers a Typha-based soilless growing media which claims to increase crop yields while reducing agriculture wastes and fertilizer costs [19]. In 2024, an engineering capstone group worked with Typha Co. to cultivate petunia flowers in Typha that had undergone different treatments including milling, composting, and pasteurization [20]. The group found success in their objectives but made several recommendations for future research including the addition of soil amendments, use of different media compositions, and improvements for the germination and growth trials.

1.1.4 Soil Amendments

A soil amendment, also referred to as a soil improver, is a substance that is applied to soil to improve its physical, chemical, and/or biological properties [21]. These materials work to

increase plant growth and improve soil fertility by increasing nutrient uptake and water availability, supporting microbiological activity, and optimizing soil properties including texture, stability, porosity, **pH**, and salinity [22]. Soil amendments can be natural or inorganic, the latter including processed or manufactured materials. Natural amendments can be classified into two groups: organic (peat, manure, biochar, plant residue), organic-mineral, or mineral (perlite, gypsum, clay minerals, volcanic ash) [23]. There are many examples of soil amendments that are used in household and commercial applications, each tailored for different applications depending on the substrate it is applied to and the plant species that will be grown. Soil amendments work to improve the structure of the soilless media while also increasing nutrient and water retention to optimize plant growth [24].

1.1.5 Germination Pods

Germination seed pods are used at the earliest stage in horticulture to germinate plants from seeds into seedlings. Most floriculture seed pods on the market are sourced from peat moss, coconut coir and rockwool [25]. These are preferred growing media due to their low **bulk density** and high-**water holding capacity** [26]. Figure 2 demonstrates examples of the current peat moss and coconut coir pods. Other critical properties include rewetting capacity, buffering capacity, and **air-filled porosity**.

Figure 2. Coconut coir pods (left) and Jiffy peat pods (right) growing Chinese cabbage seedlings.

However, they each have their own environmental concerns. Coconut coir is a natural fiber byproduct of coconut processing, however due to its high salt content it requires freshwater rinsing resulting in a saline runoff that requires further disposal [26]. Rockwool is made from

molten basaltic rock that has been spun into fibers [27]. The production of rockwool is highly energy-intensive, as it requires extremely high temperatures to melt basalt. Its disposal poses challenges due to its non-biodegradable nature. Furthermore, processing and handling rockwool can emit dust that is harmful to human health [26]. There is a gap in the market for a sustainably produced medium that can offer these properties.

1.2 Project Overview

The goal of this project is to develop an environmentally and economically sustainable seed germination pod for use in the commercial floriculture industry. Germination pods are used in hydroponic and aeroponic systems, which employ soilless growing media to optimize space and water efficiency. Peat-based germination pods are the industry standard due to peat's highly efficient nutrient absorption and release capabilities [28]. While peat is abundant and cost effective, the extraction of peat raises significant environmental concerns, particularly regarding the carbon emissions associated with the process. Building on the work of the 2024 Typha Co. capstone group, this project seeks to develop a sustainable, peat-free germination pod using an improved Typha-based growing substrate.

This project involves the improvement of a Typha-based soilless medium previously researched and tested in 2024 Capstone project [20]. To reach this goal, the effects of a variety of renewable amendments were analyzed. The selected amendments should improve the existing Typha mixture, and fulfill the technical specifications listed in Section 1.3. The selected Typha mixture was chosen based on the 2024 project's results [20], although with modifications related to the quantities to accommodate volume-based measurements instead of mass-based measurements. Tests were performed by third-party labs and by the design team to determine the properties of the Typha-amendment mix.

1.2.1 Problem Statement

The production of a Typha-based seed pod for the growth of floriculture spanning the plant's growth cycle, from germination to transplantation to soil, will provide Typha Co. with a sustainable alternative to current soilless products. This includes the development of an alternative soilless media using Typha with a suggested scalable manufacturing method to produce a viable seed pod product.

1.2.2 Deliverables

A variety of Typha mixtures composed of processed cattail and selected soil amendments were used for both germination and growth trials of floriculture. This allowed for the analysis of the performance of the soilless germination media, based on physical and chemical properties. Comparing the performance of the Typha media with current seed pods, including peat and coco coir, will provide important data for Typha Co. associated with the viability of implementing Typha-based seed pods in the market.

Additional tests were done to develop the seed pods, this involved different binders, which will allow the seed pod to withstand transportation impacts without relying on a mold. Furthermore, a manufacturing process describing an economical fabrication of the seed pods is recommended based on the selected mixture of Typha, amendment, and binder.

1.3 Technical Specifications

The technical specifications permit the evaluation of the Typha-based mixture in regard to the floriculture growth and comparing its properties with existing products. These were considered to provide ideal germinating and growth conditions to accommodate the selected seed types. Based on importance, the following technical specifications shown in Tables 1 and 2, are divided into primary and secondary items. This division was chosen based on the client's selection, with the primary specifications being the most important considerations for this project. The selected technical specifications were chosen based on the literature research done by the 2024 project. They reviewed current requirements and standards for floriculture growth and determined the criteria which would best evaluate the product and allow for comparison with current products [20]. These criteria are shown in Tables 1 and 2.

Table 1. Primary technical specifications for the evaluation of the Typha media.

Spec.	Description	Criteria*	Verification Procedure
S1.1	Water Holding Capacity	62-90%	Section 3.2.1 Appendix D3
S1.2	**Nitrogen Immobilization**	NDI>0.79	Section 3.2.2 Appendix D4
S1.3	pH	5.5-6.5	Section 3.2.3

*All criteria values are taken from the 2024 capstone report [20].

The terms included in both Tables 1 and 2 are defined in the Glossary. Table 1 represents the most important factors which determined the effectiveness of the project. Tests were performed both by third-party labs for accuracy, repeatability, and lab equipment accessibility, and by the team to assess if the criteria were reached for each soilless mixture included in this project. Table 2 identifies the rest of the required specifications considered for this project.

Table 2. Secondary technical specifications for the evaluation of the Typha mixtures.

Spec.	Description	Criteria*	Verification Procedure
S2.1	**Electrical Conductivity**	0.7-3.5mS/cm	Section 3.2.4
S2.2	**Soil Respiration**/Stability	<4 mg CO_2/g VS/day	Section 3.2.5
S2.3	Bulk Density	0.1-0.2 g/cm^3	Section 3.2.6
S2.4	**Total Porosity**	71-95%	Section 3.2.1 Appendix D3
S2.5	Air-Filled Porosity	10-31%	Section 3.2.1 Appendix D3
S2.6	**Carbon-to-Nitrogen Ratio (C:N ratio)**	20-35:1	Section 3.2.7
S2.7	**Cation Exchange Capacity**	90-140 meq/100g	Section 3.2.8
S2.8	**Phytotoxicity**	>80% Germination Index	Section 3.1.1 Appendix D2
S3.1	**Maximum Diameter**	40-60mm	Section 3.1.2
S3.2	**Height**	40-60mm	Section 3.1.2

*All criteria values are taken from the 2024 capstone report [20], excluding the maximum diameter and height specifications.

The maximum diameter (S3.1) and height (S3.2) specifications represent the final seed pod dimensions, while all the other technical specifications involve the analysis of the Typha media's properties. The specific dimensions selected are based on the slot dimensions of the hydroponic wall to maintain seed pod compatibility with the Harvest Today's "The Mega 360" hydroponic system with 2-inch Harvest Tiles used in this project.

Verification procedures were performed after the germination and growth trials were completed, as the best performing Typha-based mixtures needed to be determined. To accommodate the budget, the tests were done only for the best Typha media. Section 3 contains more details.

1.4 Limitations and Constraints

The constraints and limitations for the Typha Project are identified in Table 3, with each constraint having a corresponding plan including mitigation item(s).

Table 3. Typha Co. project constraints and mitigations strategies.

Constraint	Description	Mitigation Strategy
C1	Project is scheduled to be finished in 7 months.	• The project work was divided among the four team members. A Gantt chart was created to aid in project planning and for meeting deadlines.
C2	Allocated budget of 900$.	• Meeting with professors at the university to assess which resources are available through the university before spending money. • Meeting with clients to understand which materials will be provided without the need to spend project budget.
C3	Using a hydroponic system for floriculture growth.	• A vertical Harvest Today hydroponic wall was provided for the growing trials. • Ideal areas of the wall were identified from grow trials from previous years and will be used for this year's grow trials. This will be done to maximize the performance of each growth trial.
C4	Improving Typha media using prospective amendment choices.	• Narrowed down the amendments and binder combinations. This was done through research and consulting [redacted] (Department of Soil Science, University of Manitoba).

For the first constraint (C1), each item was assigned to a group member, and a Gantt chart was updated continuously to ensure deadlines were met to keep everyone organized.

For C2, a 900$ budget was allocated to the group. Knowing a large portion of the budget would need to be allocated for soil sample testing, the team met with university professors and the clients to understand what resources could be provided without needing to spend the budget.

For C3, an area was needed for ideal hydroponic growth. This was mitigated by the availability of the vertical growing wall located in the grain storage building at the University of Manitoba. Grow trials from the 2024 Typha Co. capstone group identified areas on the grow wall that did

not actively get the same nutrients as others [20]. The ideal areas of the wall will be used this year for the grow trials.

For C4, there could be infinite combinations of mixtures for amendments, binders, and acidifiers. Research was done to narrow down the mixture combinations to three amendments: perlite, biochar and pine fiber. [redacted] from the University of Manitoba's Department of Soil Science was consulted to evaluate the feasibility of the mixtures before attempting any grow trials.

2 DESIGN SOLUTION

To develop a media that addresses Typha Co.'s problem statement and fulfills both the primary and secondary project specifications, an improved media design based on the results from the 2024 capstone project is desired. Typha biomass constituted the main component of the soilless growing media, substituting amendments in place of peat moss to develop a sustainable alternative to peat-based soils. The following sections detail the processing methods, amendments, and media design compositions that were explored in this study. The desired growing conditions for the germination and growth trials are also specified.

2.1 Typha Processing Methods

The 2024 Typha Co. capstone projects identified three processing methods for the raw Typha including composting, milling, and pasteurizing. These processes were explored using unique combinations for a total of three media designs:

- Media Design 1 (MD1): [redacted]
- Media Design 2 (MD2): [redacted]
- Media Design 3 (MD3): [redacted]

Through the testing of nine technical specifications of the media, all three media designs were shown to improve the physical properties of the growing medium compared to the raw Typha, though to varying degrees and with some uncertainty behind the causes for this improvement. MD1 and MD2 represented the greatest performers, with MD2 being considered the "most improved" Typha-based media [20]. To build on this previous success, all three processing methods were considered for the current media design. The justifications for these methods are described in detail below.

2.1.1 Composting

Composting involves the decomposition of organic materials, in this case Typha, which decreases particle size to improve the soilless media structure and increase water holding capacity [29]. This process also improves nitrogen mobilization, making nutrients more accessible to the growing plants [30], and the heat generated throughout the decomposition works to remove pathogenic and phytotoxic substances that could inhibit plant growth from the

matured media [31]. Figure 3 illustrates physical differences between the composted Typha and its raw form.

(a) (b)

Figure 3. Physical differences for Typha compositions; (a) Raw Typha composition [20]; (b) Composted Typha blend.

In Figure 3, the composted Typha blend has a noticeable change in colour and smaller particle size compared to the raw Typha.

2.1.2 Pasteurizing

Pasteurization involves the heating of the media to a specific temperature which eliminates unwanted plant seeds and pathogens, consequently reducing its phytotoxicity, without reaching sterilization to preserve beneficial microorganisms [32]. All three of the previously studied media designs achieved pasteurization [redacted] however, this was deemed insufficient at reaching uniform heat generation to a temperature of [redacted] as recommended in the "greenhouse soil pasteurization" procedure [33].

2.1.3 Milling

Milling involves the shredding of composted Typha to further reduce the particle size and create uniformity in the composition. This increases the exposed surface area of each particle, allowing for more contact with water molecules, improving the water holding capacity of the material [20]. The 2024 capstone team completed this process using the hammermill in the Grain Storage Research Lab at the University of Manitoba with a [redacted] hammermill screen. Afterwards, a particle size distribution analysis was completed following the ASTM

D6913/D6913M-17 Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis [34]. Results from this previous test are shown in Figure 4.

Figure 4. Particle size distribution of 2024 Typha Co. capstone team media designs and peat [20].

These results indicated [redacted]. To achieve a more well-graded particle size distribution, improve air-filled porosity, and facilitate better root establishment, a larger hammermill screen size was suggested by the 2024 capstone team. The next larger nominal sized hammermill screen was be considered for use, [redacted]

2.1.4 Finalized Processes

The Typha provided for this project by Typha Co. had already undergone the processes of initial milling through [redacted] (referred to as "extruded Typha") followed by composting; thus, these procedures are not pertinent to the design methodology. The inherent variation in the composting process and maturity of the Typha materials between the previous and current years' capstone teams warranted the particle size distribution of the available batches to be reinvestigated. This was also completed by Typha Co., with the results from this test is shown in Figure 5

Figure 5. 2025 particle size distribution of raw and composted Typha compared to [redacted].

It can be observed that the particles of the composted Typha range in size up to [redacted] Additional milling using either size of the hammermill screen sizes ([redacted]) would have little effect on the overall particle size distribution, as most particles already fell under these sizes. Therefore, an additional milling process would result in an inefficient use of time and resources for this project. As such, milling was removed from the methods of interest for the design methodology.

2.2 Soil Amendments

Different soil amendments were chosen to improve the behaviour of the Typha-based soilless media for the germination and growth of floriculture. The following sections discuss the selected amendments for this project: perlite, pine fiber, and biochar.

2.2.1 Perlite

Perlite is a mineral amendment made of volcanic glass that is exceptionally porous and lightweight [35]. It is commonly used in potting soil as well as in hydroponic systems alongside other media to improve drainage and enhance aeration which promotes healthy root growth [36].

This material was included in all the media designs from 2024, and remains of interest to Typha Co. for use in their products, hence its inclusion in this project.

2.2.2 Pine Fiber

Pine fiber is a byproduct of the timber industry from the processing of pine trees which can be used as an organic soil amendment [37]. It is a fibrous and lightweight material which works to improve soil structure and retain water [38], and its decomposition enriches the soil with organic matter. Typha Co. had indicated interest in testing this material as a substitute for perlite, which was explored through the media designs.

2.2.3 Biochar

Biochar is a carbon-rich charcoal product generated through a process called pyrolysis, which involves the burning of biomass at high temperatures in anaerobic conditions [39]. When used as an organic amendment, its high porosity and large surface area allows it to improve soil conditions by retaining nutrients, providing a microbial habitat, and improving water retention [40]. Its properties largely depend on the feedstock that is used in the pyrolysis process, though the research focused on Typha biochar provided by Typha Co. to maximize the horticulture use of this renewable material. Grosshans et al. [41] produced a Typha-based biochar applicable for soil applications under International Biochar Initiative standards using plants harvested in Manitoba, showing promise for this project. There is also potential that biochar used in hydroponic media could reduce algae growth, as was found by Khan et al. [42]. The use of biochar was also recommended by the 2024 capstone team to address the shortcomings that were observed with MD1, namely water holding capacity and nitrogen immobilization.

2.3 Media Designs

Varying combinations of pine fiber, perlite, and biochar with composted Typha produced a total of 18 different compositions. They were developed alongside four control media to determine the efficacy of the renewable growing media against standard, commonly used options. The following sections describe these media in greater detail.

2.3.1 Typha-based Media Compositions

Soilless growing media using processed Typha material ( ) and some percentage of soil amendment(s) including perlite, pine fiber, and biochar were created following the composition description displayed in Table 4.

Table 4. Composition (v/v %) of Typha media mix.

[redacted]

*Media that was later eliminated from the testing phase (see Section 2.4.2).

Based on the 2024 capstone team's results, the highest performing media designs shared a consistent [redacted] ratio of growing media to perlite [redacted] [20]. This ratio served as the foundation for the media designs. To assess how variations in this ratio might affect plant performance, compositions with slightly higher and lower proportions of Typha, targeting Typha-to-perlite volume ratios of [redacted], were also tested. [redacted]. These amendments are shown in Figure 6, in addition to biochar.

(a) (b) (c)

Figure 6. Soil amendments for Typha-based media; (a) Perlite; (b) Pine Fiber; (c) Biochar.

The addition of biochar was tested in mixes [redacted]

2.3.2 Control Media

To establish reference cases for comparison, four control growing media were used: 100% extruded Typha, Jiffy peat germination pods, coco coir germination pods, and mineral rockwool cubes, as shown in Table 5. These controls represent a range of commonly used or baseline growing substrates, allowing the team to evaluate the performance of the Typha media compositions against established standards.

Table 5. Control media compositions.

[redacted]

*Media that was later eliminated from the testing phase (see Section 2.4.2).

The germination pods made of peat and coco coir are widely used in horticulture for their water retention and nutrient availability, providing points of comparison for industry-standard organic substrates. Meanwhile, the mineral rockwool cubes offers a contrasting reference as an inorganic medium known for its excellent aeration and drainage properties. Using this inert material as a control helped determine whether plant growth is influenced primarily by the growing medium itself or if the medium simply acts as a support structure for the nutrient solution delivered

through the hydroponic wall. This approach addresses concerns raised by the 2024 capstone team, who questioned whether the nutrient solution in the hydroponic wall, due to the small container volume, was directly supplying the plants with sufficient nutrients, potentially bypassing the medium's role in nutrient delivery. Together, these controls helped contextualize the performance of Typha compositions in both germination and growth trials.

2.4 Growing Conditions

The Typha-based media was tested in both germination and growth trials to assess their performance in floriculture growth, as described in the following sections.

2.4.1 Germination Trials

The germination trials were conducted in a growth chamber in the Plant Science building, following the conditions shown in Table 6.

Table 6. Growth chamber conditions for germination.

Time	Temperature	Lighting	Humidity	Fan Speed
6:00am	21°C	On	65%	60%
10:00pm	19°C	Off	65%	60%

All the conditions listed in Table 6 represent the information required for the growth chamber, following recommendations from Typha Co.

The petunia seeds, which were used in the growth trials described in Section 2.4.3, germinated using a peat-based propagation mixture provided by the Plant Science greenhouse. The seeds were planted in this mix to allow for the seedlings to grow consistently to provide better comparative results for the plant growth trials, where they were transferred to the Typha-based mixes. To support the germination, watering was done by the greenhouse staff and the team as needed to provide necessary moisture.

Approximately 200 seeds were planted initially, however only 60 well-developed seedlings germinated, as shown in Figure 7.

Figure 7. Germinated petunia seedlings from growth chamber.

This affected the plant growth trials, as four seedlings were required for each of the media options based on personal communications with Typha Co. However, the initial options included 18 mixes and 4 controls, requiring a total of 88 seedlings. Additionally, due to issues with the hydroponic wall controller, the seedlings remained in the growth chamber for a total of eight weeks, three weeks longer than anticipated, causing some seedlings to show early signs of flowering. To mitigate this, the daylight duration was reduced from 16 hours to 9 hours for the last two weeks in the growth chamber. This adjustment encouraged the plants to enter a vegetative state, preventing further flowering and reversing those already in transition. This corrective measure was implemented to ensure the seedlings were at a more consistent growth stage before planting in the Typha media, as variations in flowering could influence the results of the next stage of testing.

The second germination trial involved the planting of Chinese cabbage seeds into the Typha media and associated controls, excluding rockwool. This gave a preliminary performance of the seedling germination based on phytotoxicity (inhibition of plant growth due to phytotoxins) of the growing media. The variety of seeds were selected due to their common use as a standard assay in phytotoxicity tests, resulting from their sensitivity to this specification [43]. As phytotoxicity is a main concern for the application of Typha for germination, it was important to assess this characteristic. These trials persisted for a total of 10 days, following the recommended germination period for Chinese cabbage seeds, based in the instructions provided by the seed company.

2.4.2 Revised Typha-based and Control Media

Due to the poor establishment of petunia plants following the germination phase, the quantity of growing media had to be reduced from the originally planned media designs. As a total of only 60 seedlings were deemed fit for use in the growth trial phase, a total of 15 media options could be tested. After deliberation with Typha Co. and acquiring results from the first phase of the germination tests (detailed in Section 4.2), media options T10, T12, T13, T15, T16, T18, and C1 were eliminated from the design solutions.

2.4.3 Plant Growth Trials

The Harvest Today hydroponic wall was used for the project's growth trials. The germinated petunias were transplanted into the wall, located in the Grain Storage facility on the University of Manitoba campus. The wall has a capacity of 360 plants, and the petunias were placed in soilless media mixes, inserted following a randomized block design into the slots to minimize the influence of varying environmental conditions (see Appendix D1). The slots of the wall were filled using black netted cups with additional finer netting to prevent the media from flowing into the water system. As for the transplantation, the seedlings were taken from their molds then massaged gently to loosen the roots and free the peat mixture. However, due to the fragility of the roots, not all the mixture was removed, resulting in the transfer of this media into the plant growth trials along with the Typha mixes. The Typha media was placed in the periphery of the netting to allow the seedling to be placed in the center. The presence of peat media in the growth trials might have influenced the performance results, although with no comparative data from samples without peat, this impact cannot be ascertained.

The hydroponic system operates by pumping a nutrient solution to the top of the wall, allowing it to flow downward and nourish each port along the wall [20]. For the nutrient solution, both the pH and electrical conductivity were measured to assess its adequacy, using a Bluelab combo meter. The ideal range for the pH is [redacted], therefore a pH down solution is required to bring down the pH of the neutral water. As for the nutrients, the concentrations used for the 20-20-20 fertilizer follows the directives from its package. Initially, the concentration of 100 ppm of nitrogen was provided by the nutrient solution, with a gradual increase to 200 ppm over a two-week period. The watering and lighting schedule for plant growth are found in Table 7.

Table 7. Hydroponic wall growth conditions.

Watering Duration	Watering Frequency	Lighting Duration*	Lighting Intensity*	Sunrise/Sunset Duration*
1 minute	Every 4 hours (changed to every 4.8 hours after three weeks, due to expert observation of overwatering)	16 hours (start at 8:15am)	40%	30 minutes

*Based on results from the 2024 capstone report [20] and represents options for the Theia Stratus mobile app for the lighting conditions.

The watering frequency and duration for the hydroponic wall was set by the controller on the Harvest Today wall. For the lighting schedule, the Theia Stratus app was used to control the three Raging Kale lights with a 16-hour cycle to incite growth. Before starting the trial, the wall was thoroughly cleaned to prevent cross-contamination. The layout of the seedlings in the hydroponic wall is shown in Figure 8.

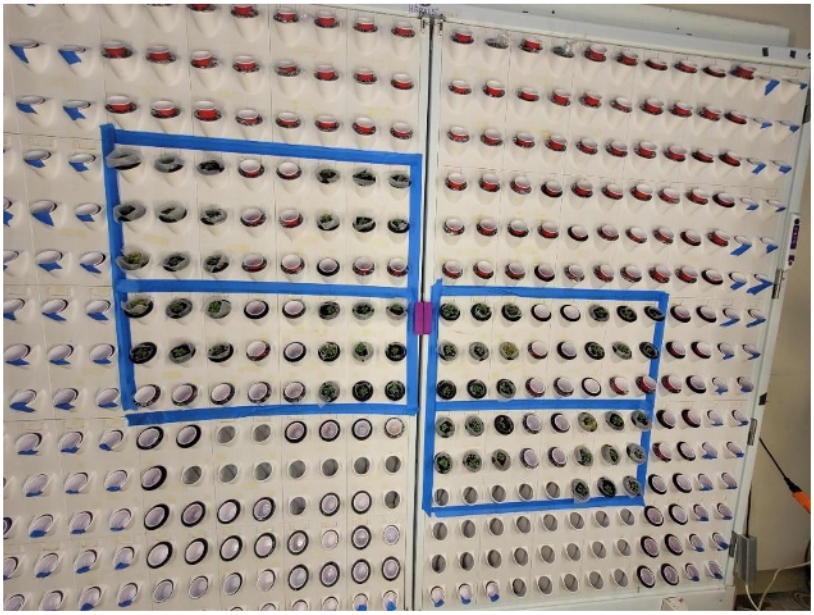


Figure 8. Hydroponic wall layout with randomized block design; blue outlines represent the blocks.

Based on the recommendations provided from last year's capstone group, the extra holes in the wall were covered using plastic cups [20]. This was done to limit the evaporation from the watering system, prevent water from splashing out of the empty slots, as well as limit the exposure of light reaching the water tank to reduce algal growth. The initial placement of the

cups inside the black netted cups did not prevent water from pouring out of the slots, as water circumvented them. As a solution, most of the netted cups were covered with either plastic wrap or plastic bags, with the aim of better sealing the junction of the cup and slot. This reduced the volume of water exiting the system, although containers were still laid in front of the wall to collect any excess water.

2.5 Seed Pod Design

For the Typha-based media to be used as a germination seed pod, it needs to retain its conical/cylindrical shape and structural integrity when being handled and during use. Technical specification defines the height and maximum diameter of the seed pod within the range of 40-60 mm. Various binding agents are tested to evaluate their adhesive strength within the media. Different alternatives for binders are described in the following subsections.

2.5.1 Agar

Agar is a polysaccharide which is derived from red algae. It is commonly used as a gelling agent [44]. It forms into a gel when mixed with water and heated. The gel would ideally mechanically support the seed pods' structure while also maintaining the media's porosity for seed germination and root growth [45]. Agar is biodegradable, which would align with Typha Co.'s sustainability plans. The limitations with agar could be its sensitivity to become brittle when dried [46] and the potential of mold growth.

2.5.2 Flaxseed Mucilage

Mucilage is a protective biofilm found in plant seeds. It is made up of polysaccharides that form a gel-like substance around the seed. Flaxseeds were chosen as the mucilage source as they are known for high mucilage yields [47]. When extracted, mucilage can be used as a water-based glue [48]. This will facilitate binding of the substrate, with adhesion increasing with dehydration. The procedure for the extraction can be found in Appendix B.

2.5.3 Yucca Powder

Yucca powder is derived from roots and stalks of plants in the Yucca genus, which are perennial succulent desert plants [49]. Yucca exhibits bio-stimulant properties and has been shown to enhance germination and early growth in plants subjected to drought or salt stress [50]. The

powder readily absorbs and releases water, aiding in moisture retention and contributing to substrate cohesion which could improve substrate binding properties.

2.5.4 Molasses

Molasses is a viscous byproduct obtained during the extraction of sugar from sugar cane or sugar beets. It consists of residual sugars, crude protein, organic acids, and minerals [51]. It is often used as a soil amendment because it supplies carbohydrates to soil microbes and improves soil structure due to its viscous properties [52]. Molasses is extremely adhesive and hardens when dried which provides structural support to the substrate while also promoting plant growth.

2.6 Manufacturing

The manufacturing process is closely related to binder selection, as it involves forming seed pods from the Typha-based mix. A manual seed pod manufacturing procedure is necessary to understand material behavior before developing a scaled automated process. The manual manufacturing process for seed pod testing is outlined in the following steps:

Steps for Production:

1. Binder preparation:
2. Mixing:

[redacted]

Using a stirring rod, mix the Typha-based substrate with the binders [redacted]

3. Shaping:

[redacted]

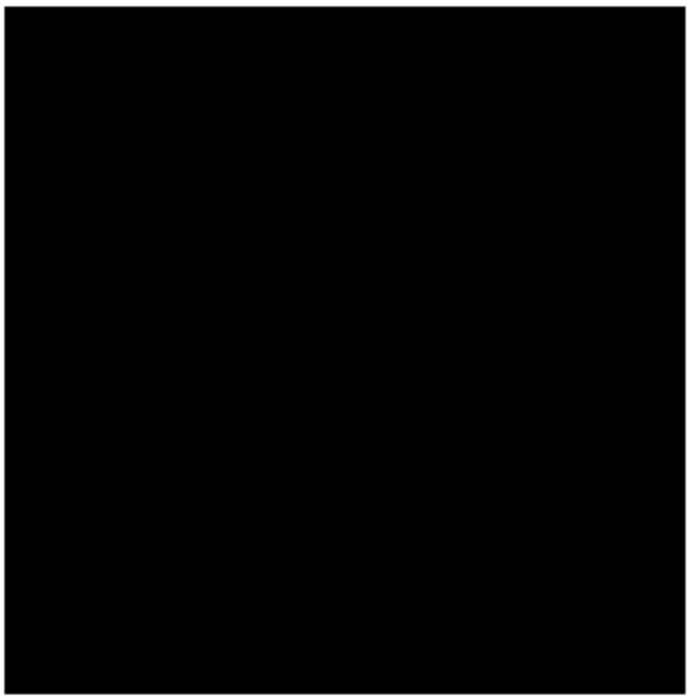


Figure 9. Slotted hydroponic wall net cup used as the seed pod mold.

3 DESIGN EVALUATION

To assess the performance of the soilless media and to identify its properties with respect to the identified technical specifications, various tests and measurements were performed. Third-party testing was utilized to ensure professional practice was followed and to achieve highly reliable results; otherwise, internal testing was completed by the team to accommodate the project budget. The following sections describe these specifics, while the results are discussed in Section 4.

3.1 Internal Verification Procedures for Technical Specifications

These tests involved the measurement of the media's physical and chemical properties, which work to support the development of floriculture. The procedures were done by the capstone team in facilities at the University of Manitoba. Internal testing covered phytotoxicity (S2.8), diameter (S3.1), height (S3.2), water holding capacity (S1.1), total porosity (S2.4) & air-filled porosity (S2.5), and nitrogen immobilization (S1.2). The rest of the tests were sent to a third-party laboratory.

3.1.1 Phytotoxicity (S2.8): Germination Trials

The phytotoxicity of the Typha-based media affects the ability of seeds to successfully germinate and is a major concern associated with the use of cattail for this process, as concluded from expert consultation. Chinese cabbage seeds are commonly used for this testing procedure as they are highly sensitive to phytotoxins and widely accepted as the ideal bioindicator for assessing soil toxicity and seed germination inhibition [43]. The following procedure, summarized in Table 8, covers the determination of the germination index (GI) for both the control and the Typha samples. The procedure is adapted from Emino and Warman [43] and Warman [54].

Table 8. Phytotoxicity (S2.8) verification procedure summary.

Spec.	Passing criteria	Materials	Procedure Summary	Reference Procedure
S2.8	GI > 80%	• 120 mL distilled water • 9 g of sample (3g per sample) • Four 250 mL beakers	A distilled water control and diluted media samples are compared using Chinese cabbage seed germination performance. Refrigeration and incubation of the	Appendix D2

Spec.	Passing criteria	Materials	Procedure Summary	Reference Procedure
		• Magnetic stirrer • Centrifuge • Four centrifuge tubes • Refrigerator • Four filter papers • Four 90 mm petri dishes with lids • Forty Chinese cabbage seeds • Incubator • Calipers	samples for a six-day period allows for the germination index to be measured. This is done by measuring the length of the roots and counting the number of germinated seeds at the end of the test.	

The detailed procedure and equations for the germination index (GI) calculations are found in Appendix D2. As shown in Table 8, the expected value will be higher than 80% to pass the technical specification criteria.

3.1.2 Diameter (S3.1) & Height (S3.2): Hydroponic Wall Growth Trials, Manufacturing

Current seed pods on the market are typically cylindrical and have a diameter and height ranging from 40-60 mm [54], [55]. Producing seed pods of this size will aid in transitioning consumers from existing products to the Typha-based alternative for both greenhouse and home applications. It should be noted that the growth trials occurred in the Harvest Today hydroponic wall, which is configured with 50.8 mm diameter growing slots and was therefore selected as the desired size of the pod to ensure compatibility. A mold was created following the dimensions of the growing slots, consisting of a truncated cone with a base diameter and height of 50.8 mm. After sufficient drying time to allow for full contraction, the diameter and height of the seed pods were measured to ensure compliance with dimensional requirements.

3.1.3 Water holding capacity (S1.1), Total Porosity (S2.4) & Air-Filled Porosity (S2.5)

The water holding capacity, total porosity, and air-filled porosity specifications can be determined based on one procedure resulting from volume measurements. This procedure is adapted from the British Columbia Ministry of Agriculture Factsheet for media aeration [56] and summarized in Table 9.

Table 9. Water holding capacity (S1.1), total porosity (S2.4), and air-filled porosity (S2.5) verification procedure summary.

Spec.	Passing criteria	Materials	Procedure Summary	Reference Procedure
S1.1 Water holding capacity **S2.4** Total porosity **S2.5** Air-filled porosity	62-90% 71-95% 10-31%	• Container • Plug or stopper • Graduated cylinder • Collecting pan	Involves the measurement of the volume of the container, followed by slow saturation of the media. Free water is then allowed to drain from the media. Several volume measurements are taken to calculate the three specifications; including the container volume, the volume of water required to reach saturation, and the volume of water drained from the saturated media.	Appendix D3

The detailed procedure and equations for the individual specification calculations are found in Appendix D3.

3.1.4 Nitrogen Immobilization (S1.2)

This parameter involves the availability of nitrogen in soil for plant use. This test assessed the amount of immobilized nitrogen in the media, with smaller values approaching zero representing a higher immobilization, with values near 1 having lower immobilization. As can be shown in Table 10, a higher value is preferable. This procedure is adapted from Dombrowsky [57] and the 2024 capstone report [20].

Table 10. Nitrogen immobilization (S1.2) verification procedure summary.

Spec.	Passing criteria	Materials	Procedure Summary	Reference Procedure
S1.2	NDI > 0.79	• One seedling tray with drainage holes with minimum 4 cells with a volume of 100 mL each • 400 mL of media (100 mL per cell)	The media is placed in the 4-cell tray and tapped to remove any air gaps. Cyclic applications of the deionized water and potassium nitrate solution are done to the media, with drainage allowed in between applications.	Appendix D4

Spec.	Passing criteria	Materials	Procedure Summary	Reference Procedure
		• Rack (to allow draining) • Bin (to hold volume of draining liquid) • 800 mL of deionized water • 800 mL of potassium nitrate (KNO_3) solution • Four filter papers • Incubator • Four 400 mL beakers • Stirring rod • Two funnels • Four 0.45-micron syringe filters • Four syringes • Four 10 mL glass collection vials • Parafilm • Flow Injection Analyzer for NO_3-N concentration	Two of the cells are then mixed with deionized water and filtered. The nitrogen content in the filtered solution is then measured using the Flow Injection Analyzer. The remaining two cells will remain in an incubator for 4 days before also being filtered and analyzed. Both readings will allow for the calculation of the NDI.	

The expected results will have a nitrogen drawdown index (NDI) higher than 0.79 to pass the specification criteria. The detailed procedure and equations for the specification calculations are found in Appendix D4.

3.2 External Verification Procedures for Technical Specifications

Third-party testing was completed by A&L Canada Laboratories Inc. This laboratory was selected based on the reliable partnership that had been initiated by Typha Co. who utilized their services for prior soil and compost testing. The high associated costs for the testing done by A&L Laboratories limited the use of this method for all technical specifications included in this section. Using results provided by a professional laboratory increased their accuracy and replicability. This provided Typha Co. with more conclusive results for the performance of the Typha media. Third-party testing was done for pH (S1.3), electrical conductivity (S2.1), soil

respiration/stability (S2.2), bulk density (S2.3), C:N ratio (S2.6), cation exchange capacity (S2.7), and a nutrient analysis for comparison between the selected Typha media.

Table 11. Desired technical specification verification criteria for external testing.

Technical Specification	Pass/Fail Criteria
pH (S1.3)	5.5-6.5
Electrical Conductivity (S2.1)	0.7-3.5 mS/cm
Soil Respiration/Stability (S2.2)	<4 mg CO_2/g VS/day
Bulk Density (S2.3)	0.1-0.2 g/cm^3
C:N Ratio (S2.6)	20-35:1
Cation Exchange Capacity (S2.7)	90-140 meq/100g

Samples were sent to the A&L Canada Laboratories Inc. to be analyzed. Due to confidential procedures, only the test results were provided.

3.2.1 Nutrient Analysis

Samples were sent to A&L Canada Laboratories Inc. for a compost analysis to determine nutrient and organic matter content. Due to confidential procedures, only the test results were given. This provided comparative data for all the tested soilless media.

3.3 Growth Trials Verification Procedures

To assess the performance of the Typha-based growing media at supporting and sustaining plant development, key plant quality indicators were assessed for each of the plants during and at the end of the growth trials. These indicators, including their method of evaluation and significance, are summarized in Table 12.

Table 12. Assessment indicators of plant quality.

Plant Quality Indicator	Evaluation Method	Significance
Plant Height	Measurement	Reflects vertical vegetative growth
Plant Width	Measurement	Indicates lateral vegetative growth
Number of Flowers	Visual Count	Measures reproductive success and ornamental quality
Frequency of Flowering	Visual Count	Assesses the occurrence of flowering cycles
Fresh Weight	Measurement	Represents total biomass development
Root-to-Shoot Ratio	Measurement	Evaluates biomass allocation between root (below soil) and shoot (above soil) growth
Mortality Rate	Visual Count	Signifies the number of plant deaths

These indicators of plant quality were selected based on the 2024 Typha Co. capstone project [20], which utilized indicators suggested by Gallegos-Cedillo et al. [58] and recommended the addition of root-to-shoot ratio as a more informative plant quality metric. The frequency of flowering was also added to assess the plant's ability to sustain continuous blooming cycles, as this is a desirable trait to floriculture. Additionally, plant mortality was tracked to account for plant loss during the duration of the growth trials.

The height and width of the plants were measured using calipers. Plant height was measured from the top surface of the growing media to the tallest point in the plant. The plants were gently straightened, either by stretching upright or laying them on their side, to ensure an accurate measurement. Plant width was measured along two axes, one representing the longest horizontal spread of the foliage and the other perpendicular to the first. These two measurements were taken to account for variations in plant growth and asymmetry, providing a comprehensive assessment of the plant's width. The average of these measurements was then used as the overall plant width.

A visual count of the quantity of flowers on each plant was conducted at the completion of the growth trials. This value included all flowering stages, including the buds, active blooms, and spent (dead) flowers, allowing for a more representative measure of flowering output despite the single timepoint assessment. The frequency of flowering was recorded throughout the growth trials, recording a count for the occurrence of each new bloom on the plants.

Fresh weight was measured using an electronic scale after removing all growing media from the plants root system to obtain the total biomass of the plant. To better understand the distribution of the biomass, the weight of the roots (below-ground biomass) and shoots (above-ground biomass) was also measured after carefully separating the plant using a sharp knife.

Lastly, plant mortality was assessed by recording the number of plants that died at any point during the growth trials. This metric provides insight into potential stress factors within the growing media that may have limited plant survival and overall growth performance, ultimately resulting in plant loss.

3.4 Seed Pod Verification Procedures

To assess the performance of the seed pods, determining their resistance to impacts and re-wetting capabilities is essential for the distribution, transportation, and use of the seed pods. As transportation can result in damage to the seed pods, ensuring their resistance to such impacts would be essential for the final product. Additionally, Typha can become hydrophobic if allowed to dry completely, therefore the water absorption test would represent the behaviour of the seed pods after its distribution.

3.4.1 Preliminary Binder Testing

As research on binding agents for soilless substrates is limited, preliminary experiments are necessary to evaluate the efficacy of potential treatments. The binding agents listed in Section 2.5 were applied to the substrate mixture and formed into seed pods, allowing for qualitative observations of the resulting pod's structural properties and texture. The details of each treatment concentration within the media are provided in Appendix D5. The treatment that demonstrated the most effective binding properties were then tested at varying concentrations, outlined in the following subsections, providing quantitative data on binder performance.

3.4.2 Impact Testing

To evaluate the strength of the binding agents within the seed pod, impact testing was conducted to simulate the forces experienced during the shipping and transportation process. The test involves dropping the pods from various heights to assess their structural integrity and failure threshold. The detailed procedure for this test is provided in Appendix D6.

3.4.3 Water Absorption Testing

A water absorption test is conducted to evaluate how different binding agents and compression during manufacturing influence the seed pod's water-holding capacity and rewetting ability. The test involves applying a small volume of water to each fully dried pod to simulate hydroponic watering, followed by a qualitative assessment of infiltration rate and hydraulic conductivity. The Typha-based media was tested in germination and growth trials, assessed based on chemical and physical properties, and combined with binders to determine their potential for commercial

seed pods. The procedures in Section 3 discuss the tests and metrics which were used for this project. The results for these are discussed and analyzed in the following section.

4 DESIGN RESULTS

The design assessed both physical trials and chemical properties of the Typha media, as well as considering options for the seed pod manufacturing process. Considering the behaviour of the media in both germination and growth trials helped identify which media permitted the development of plant seeds with comparison to current market options. The binder testing allowed for the development of seed pods for commercial distribution, also to be used with the suggested manufacturing process.

4.1 Technical Specification Results

The first test performed on the media involved the calculation of the phytotoxicity. This test described in Section 3.1.1 involved the germination of Chinese cabbage seeds in the diluted media, with the deionized water (DI) acting as the control for all the tested samples. The results from this test are summarized in Table 13.

Table 13. Phytotoxicity (S2.8) results (GI: Germination Index).

Results	T1	T2*	T3	T4	T5	T6	T7
GI (%)	171	100	171	162	167	162	174
Pass/Fail (>80%)	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Results	**T8***	**T9**	**T11***	**T14***	**T17**	**C2**	**-**
GI (%)	182	174	189	206	232	129	-
Pass/Fail (>80%)	Pass	Pass	Pass	Pass	Pass	Pass	-

*Selected for further testing.

As shown in Table 13, the mixes selected for the growth trials all passed the Pass/Fail criteria of 80%. It should be noted that some of the other controls used in the growth trials are excluded in this test, as it was assumed that the rockwool and coco coir would not have any problems regarding their phytotoxicity due to their already common use as germination media. However, the peat was included to provide a comparison between the Typha media and the current market product.

The GI calculations depend on the results from the DI samples, with a value of 100% representing the same germination behaviour in the Typha media and the control. Due to all the mixtures performing better or the same as the DI control, it can be concluded that the selected

media do not have phytotoxic properties which would hinder plant germination. The calculations for the phytotoxicity test are found in Appendix D2.

The lowest GI for the tested mixtures was T2, which was noted to have dry filter paper in one of its three Petri dishes, with a second being semi-dry. The reason for this is unknown, as all dishes were placed in the same incubator and provided with the same volume of diluted media. However, this likely affected its resulting GI and might not be correlated with the presence of phytotoxicity, as 27 out of 30 seeds still germinated. The lower score is a result of a shorter mean root length with respect to the other media, although still comparable to the control result.

The results from this test helped assess which of the Typha-based mixtures should be further tested, both internally and externally. While the best results from the germination, growth, and phytotoxicity tests should be prioritized, testing a wider range of mixtures was preferable to meet the client's request. Therefore, mixes T2, T8, T11, and T14 were selected for further analysis. The results for these media are shown in Table 14, either in red or green to represent the media's success or failure (pass = green, fail = red).

Table 14. Results for technical specifications for T2, T8, T11, and T14.

Spec.	Description	Pass/Fail Criteria	Verification Procedure	Results			
				T2	T8	T11	T14
S1.1	Water Holding Capacity (%)	62-90	Section 3.2.1 Appendix D3	45.03	41.01	34.82	48.7
S1.2	Nitrogen Immobilization	NDI>0.79	Section 3.2.2 Appendix D4	0.173*	0.038*	0.052*	0.040*
S1.3	pH	5.5-6.5	Section 3.2.3	8.8	8.2	8.5	8.0
S2.1	Electrical Conductivity/ Soluble Salts (mS/cm)	0.7-3.5	Section 3.2.4	1.0	0.7	1.0	2.2
S2.2	Soil Respiration/ Stability (mg CO_2/g VS/day)	<4	Section 3.2.5	2.30	2.30	2.30	2.30
S2.3	Bulk Density (g/cm^3)	0.1-0.2	Section 3.2.6	0.337	0.338	0.478	0.368
S2.4	Total Porosity (%)	71-95	Section 3.2.1 Appendix D3	59.16	58.12	58.12	58.64
S2.5	Air-Filled Porosity (%)	10-31	Section 3.2.1 Appendix D3	14.14	17.02	23.30	9.95

Spec.	Description	Pass/Fail Criteria	Verification Procedure	Results			
				T2	T8	T11	T14
S2.6	Carbon-to-Nitrogen Ratio (C:N ratio)	20-35:1	Section 3.2.7	17:1	19:1	21:1	24:1
S2.7	Cation Exchange Capacity (meq/100g)	90-140 meq/100g	Section 3.2.8	28.3	21.3	20.5	24.8
S2.8	Phytotoxicity (%GI)	>80% GI	Section 3.1.1 Appendix D2	Summary in Table 13			

*The results for the nitrogen immobilization are included in this Table, but do not accurately represent the behaviour of the media as the tests were not performed as described in its procedure (Appendix D4).

The calculations for the nitrogen immobilization (S1.2), water holding capacity (S1.1), total porosity (S2.4), and air-filled porosity (S2.5) are found in Appendix D3 and D4. The results provided by A&L Laboratories for the technical specifications and nutrient analysis are in Appendix F.

As shown in Table 14, the water holding capacity failed to reach the pass/fail criteria, with mix T14 [redacted] having the highest value. Improving the media by 13.3% would make the Typha media reach the lower end of the acceptable range.

Due to issues with laboratory equipment availability, the results for the nitrogen immobilization do not accurately represent the media. The samples were prepared according to the described procedure in Appendix D4; however, the Flow Injection Analyzer was run several days later, therefore making the results invalid.

Table 14 shows that all the tested media failed the pH requirement for optimal floriculture growth, with T14 having the most acidic pH. The basic pH was expected based on independent research conducted by Typha Co. Additionally, it is likely that the pH affected the initial germination trials with Chinese cabbage seeds and resulted in the low germination rate. As the phytotoxicity of the samples was not a concern for the development of the seeds, the high pH might have hindered their development.

The electrical conductivity or soluble salts passed for all the selected media, with [redacted] just passing within the range. This test was performed by A&L Laboratories and provided the results as soluble salts. Both electrical conductivity and soluble

salts have the same units and represent the ion concentration in the mixture. However, soluble salts represent the critical component of electrical conductivity that has a greater impact on plant performance.

The stability results represent data for the composted Typha used for all mixes. Therefore, all tested samples have the same value. This test was performed independently by Typha Co. due to the high associated cost of this procedure. The results demonstrate that the composted Typha had adequate stability for its use as compost in the media design.

The bulk density for both the [redacted] mixes, T2 [redacted] and T8, is lower than the [redacted] mixes, with T11 [redacted] having the highest result. It can be concluded that the addition of [redacted] increases the bulk density of the media, while [redacted], when used in combination, can help reduce it.

The total porosity results of all four samples are all within an approximate ±1% range to each other, with mixes T8 and T11 having identical values. Based on the closeness of the results, it can be assumed that differences between perlite, pine fiber, and biochar is negligible.

A more noticeable difference is seen in the results for air-filled porosity, which is a metric closely related to the total porosity of a mix. All mixes meet this criterion except for T14, which narrowly fell outside the allowable range. While T14 did fail this specification, its result falls almost at the lower end of the criteria and could be assumed to be adequate in its behaviour.

The carbon-to-nitrogen ratio exhibits the widest range of results, with half of the mixes meeting the criteria. Both [redacted], T11 and T14, gave values within the selected range and therefore performed better than the [redacted]

All mixes failed to meet the cation exchange capacity criteria, as their results ranged much lower, between 20.5 and 28.3 meq/100g, compared to the required range of 90-140 meq/100g.

In Table 14, the phytotoxicity specification was excluded as it was previously discussed in Table 13. As for the height and width requirements, they will be discussed in Section 4.4.1.

To identify the best performing mix according to their technical specifications results, they were ranked in Table E1. All results which passed the criteria were given the full allotted points, for the results that failed the criteria they followed a point system. The best performing with the

highest points, followed by the next performing results with a proportional decreasing score. An added weight for the primary specifications (S1.1, S1.2, and S1.3) allowed for these results to impact the results more significantly due to their importance for media behaviour. The highest result in the ranking demonstrates the overall best media in terms of the technical specifications. The nitrogen immobilization results were excluded from the ranking as they are not valid for analysis. The final ranking is shown in Table 15, where the higher value indicates the better performer.

Table 15. Technical specifications ranking results.

Treatment	T2	T8	T11	T14
Ranking	35	34	29	43

Overall, based on the technical specification rankings, mix T14 performed the best, followed by mixes T2 and T8. This ranking allows to assess the relative behaviour of the media, however, there are still many results that did not pass the technical specification criteria.

A comparison of the MD2 mix results from the 2024 capstone project and the T14 media helps illustrate the improvements and consistency between the best performing media from both years. Table 16 demonstrates the differences and variations between the 2024 and 2025 results, where both results' columns are shown in red (fail) or green (pass). The last column in the table compares the old and new results, where (+) is an increase, (-) is a decrease, red shows that a new result is worse than the 2024 result, and green shows an improvement.

Table 16. Comparison of selected technical specifications of this year's T14 mix with the 2024 capstone project MD2 [20].

Spec.	Description	Criteria	Results (2024) for MD2*	Results (2025) for T14	Results Comparison
S1.1	Water Holding Capacity	62-90%	22.17%	48.7%	+119.7%
S1.2	Nitrogen Immobilization	NDI>0.79	0.70	0.040	-
S1.3	pH	5.5-6.5	8.2	8.0	-0.2
S2.1	Electrical Conductivity	0.7-3.5mS/cm	1.8 mS/cm	2.2 mS/cm	-
S2.2	Soil Respiration/ Stability	<4 mg CO_2/g VS/day	3.10 mg CO_2/g VS/day	2.30 mg CO_2/g VS/day	-
S2.3	Bulk Density	0.1-0.2 g/cm^3	0.21 g/cm^3	0.368 g/cm^3	+75.2%

Spec.	Description	Criteria	Results (2024) for MD2*	Results (2025) for T14	Results Comparison
S2.4	Total Porosity	71-95%	49.56%	58.64%	+18.3%
S2.5	Air-Filled Porosity	10-31%	27.39%	9.95%	-63.7%
S2.6	Carbon-to-Nitrogen Ratio (C:N ratio)	20-35:1	14:1	24:1	+71.4%
S2.7	Cation Exchange Capacity	90-140 meq/100g	40.9 meq/100g	24.8	-39.4%
S2.8	Phytotoxicity	>80% Germination Index	78.7%	206%	+161.8%

*This data is taken from the 2024 capstone project report [20].

The changes between both media show the areas where this project improved its properties, and where they are still lacking. The percentage change equation was used to calculate the differences between results, except for pH, which only shows the decrease in the same units. This equation involves the difference between the results, divided by the old results, and multiplied by 100%.

Additionally, the change for electrical conductivity and soil respiration/stability was not calculated due to these results passing the criteria both in 2024 and 2025. The nitrogen immobilization was also not compared, as the T14 results are invalid.

Comparing the other results, only the bulk density, air-filled porosity, and cation exchange capacity reduced in performance relative to the desired range. For all these technical specifications, T14 was not the best performing. T2 (30% perlite) performed better than T14 for all these metrics, therefore it could be assumed that adding some perlite to the pine fiber and biochar mix could improve these properties.

As for the remaining technical specifications, T14 improves significantly upon the behaviour of last year's results. Notably, the primary specifications improved in performance, which represent the crucial component of the Typha-based media to provide optimal growth. For all the specifications from the 2024 capstone project that passed the criteria, mix T14 consistently remains in the passing range, excluding the air-filled porosity, which marginally missed the lower end of the allowable range.

4.1.1 Nutrient Analysis Results

Nutrient analysis evaluated the organic matter, micronutrient, and macronutrient content of the four Typha-based media compositions selected for external testing. The results from this testing are summarized in Table 17, with the values in green indicating the nutrients that are within the ideal range and those in red representing potential concern for nutrient exceedances.

Table 17. Nutrient analysis results.

[redacted]

Both the soil organic matter (SOM) and concentrations of plant-available nitrogen (both in the forms of nitrate and ammonium) fluctuate with time and changing soil conditions, including temperature and water content [59], [50]. However, it is also known that higher SOM can increase water holding capacity, nutrient content, and microbiological activity as well as improve soil structure [59], [60]. Therefore, the high contents of SOM in mixes T11 and T14 could support greater plant development compared to the lower levels. All of the mixes had the same concentration of Nitrate-N, [redacted], despite differences in SOM content.

All four of the tested soils show high concentrations of both macro- and micro-nutrients, with [redacted] being found compared to standard control values for germination media.

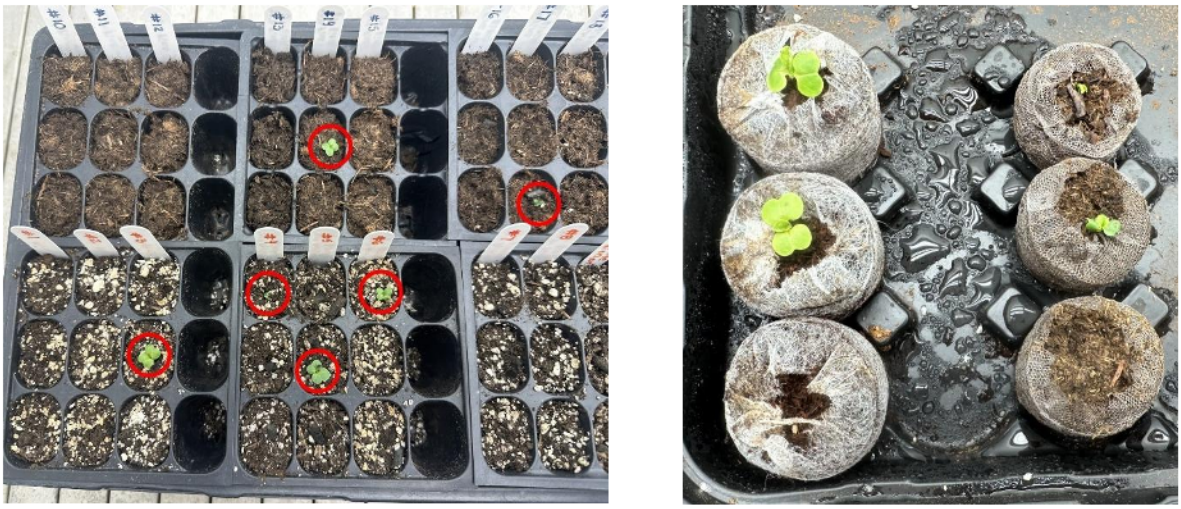
This suggests that these Typha-based mixes have the potential to support early plant development, though certain elements, particularly the macronutrients, may require further optimization to avoid potential toxicity effects. Of the four mixes, T8 fell within the ideal range of nutrient content for the most elements, followed by T11 and T14, each meeting the standard for three elements, and lastly T2, which met the standard for two elements. It is also important to note that the availability and required concentrations of these nutrients to the plants will change depending on its growth stage, and fertilizers are recommended to account for their depletion.

4.2 Germination Trial Results

The germination trials involved the growth of Chinese cabbage in the Typha-based growing medias, as well as petunias in a greenhouse peat-based growing medium. The Chinese cabbage germination trials in the various Typha-based media allowed for the designs to be evaluated based on their ability to germinate a plant species that is highly sensitive to compost maturity, serving as a rigorous test of its viability as a soilless growing medium. The petunia seeds were planted in a standard growing media to ensure consistent plant development prior to their transplant in the hydroponic wall for the growth trials. The following sections share the results from both of these trials.

4.2.1 Chinese Cabbage Germination in Typha

Three replicates, each planted with one Chinese cabbage seed, were used to evaluate germination across the Typha-based growing media. This included the original 18 Typha-based mixes (T1–T18) and three controls: [redacted] The seeds were germinated over a 10-day period (January 12–22), in accordance with the supplier's recommended germination time. After this period, the number of successfully sprouted seedlings was recorded, as shown in Figure 10.



(a) (b)

Figure 10. Germinated Chinese cabbage seeds after 10 days in Typha-based growing media; (a) Typha-based growing medias T1-T18, red circles indicating the successful germinations; (b) control medias C2 (right) and C3 (left).

Among the Typha-based mixes, T3, T4, T5, T6, T14, and T17 each had one successful germination. Controls C2 and C3 performed better, with two germinations each, while C1 showed no seedling emergence (not pictured). Notably, the Typha-based mixes containing [redacted] accounted for four of the six successful germinations, yielding a germination rate of 14.8%, whereas mixes with [redacted] media produced only two successful germinations (7.4%). These results suggest that [redacted] may better support Chinese cabbage germination compared to [redacted]. Additionally, the Typha-based treatments incorporating [redacted] (T4, T5, and T6) exhibited the highest germination success among the Typha-based mixes. This indicates that a conservative proportion [redacted], in combination [redacted], may enhance Chinese cabbage germination. As Chinese cabbage is highly sensitive to substrate maturity, successful germination of this seed suggest that the growing media provides a suitable environment for early plant development, making it equally suitable in floriculture applications.

4.2.2 Petunia Germination in Peat

The germination of petunia flowers persisted for nearly two months, beginning on December 4th, 2024 and ending on January 31st, 2025. 192 cells were originally planted with one seed each, and a germination success rate of 90% was expected based on the supplier's information [61]. When the seedlings first emerged, it was observed that several of the seeds had migrated to a

neighbouring cell, resulting in several cells containing more than one seedling. Figure 11 shows one instance of this seed migration.

Figure 11. Duplicate germination of petunia plants (photo taken December 30th, 2024).

Bottom watering was utilized throughout the germination phase, which allowed the trays to sit in and slowly uptake water using capillary action as to not disturb the soil. However, the seeds were initially laid atop the soil surface and sprayed with water to dissolve their clay-coating, as recommended in the suppliers planting instructions. This likely caused some of the seeds to be carried away from their intended position due to the small size of these seeds coupled with the force of the water being sprayed onto them. Though these duplicates were observed early into the growing phase, they were left alone to establish themselves, ensuring that at least one of the seedlings would be viable for transplantation. On December 17th, 2024, a total of 90 individual cells had successful emergence, not counting the duplicates. As this number was significantly lower than what was originally projected for, the number of Typha-based media that could be tested for the growth trials while achieving four replicates ultimately had to be scaled back.

The seedlings were allowed to continue growing until they had developed several true leaves, ensuring they were sufficiently established prior to transplantation. This extended growth period also accommodated delays in the setup of the hydroponic wall, which was not yet operational due to unforeseen updates being implemented by the manufacturer. Maintaining the seedlings in the peat-based medium during this time ensured that they remained healthy and viable for the upcoming growth trials. Figure 12 displays the petunia seedlings at the half-way point and completion of the germination growth stage.

(a) (b)

Figure 12. State of petunia germination on; (a) December 30th, 2024 (Day 26); (b) January 31st, 2025 (Day 58).

Based on the low number of petunias that had reached sufficient size by the end of the germination stage, only 15 of the growing media could be evaluated in the growth trial stage. The mixes that were eliminated were determined based on the initial Chinese cabbage germination test results, which indicated that the [redacted] were less effective in supporting seed germination. As a result, only [redacted] was retained for further evaluation, thereby eliminating T10, T12, T13, T15, and T16. As C1 failed to establish any successful germinations through this test, it was also eliminated from the proceeding growth trial phase. This selection process helped refine the number of growing media that would be tested in the growth trials while prioritizing mixes that showed the most promise for plant establishment. Therefore, the tested growing substrates were reduced to the following: Typha-based mixes T1-T9, T11, T14, and T17, as well as control mixes C2-C4.

4.3 Growth Trial Results

The growth trial lasted 41 days, starting January 31st until March 12th. This trial lasted longer than the expected four weeks to allow for the plants to further develop. In the first weeks, the nutrient solution was gradually increased from 100 ppm to 200 ppm. Once the plants received the higher nutrient concentration, they became greener, and the number of leaves increased. This growth response was likely due to the nitrogen in the 20-20-20 nutrient solution, which promotes foliage development and overall biomass production [62], [63]. The increase in biomass and foliage were observed and can be shown in Figure 13.

(a) (b)

Figure 13. Change of nutrient solution concentration effect; (a) February 14th, 2025: grown in 150 ppm; (b) February 24th, 2025: grown in 200 ppm.

After approximately three weeks the leaves began to show signs of chlorosis (yellowing). Once the watering cycle was reduced to every 4.8 hours, the plants showed significant improvement of their performance, as shown in Figure 14.

(a) (b)

Figure 14. Comparison of Block 3 of the growth wall; before and after watering cycle change; (a) Before: visible chlorosis in leaves; (b) After: decreasing chlorosis in leaves.

Near the end of the trial, the controller stopped working due to water damage. This resulted in wilting of the leaves and stems, as shown in Figure 15.

Figure 15. Wilted leaves on petunia plant from lack of water.

As this was close to the end of the trial, only some of the plants recovered from the water scarcity. The subsequent measurements for the average plant height and width, as well as the weight of the samples were affected by this event.

Only six of the total mixes produced flowers, including T2, T3, T6, T7, T8, T14, and C4, as represented in Table 18. Of these mixes, only T6, T8, and C4 had more than one of the plants reach the flowering stage.

Table 18. Growth wall plant dimensions, flowering success, and growth quality indicators.

Samples	Average Plant Height (mm)*	Average Plant Width (mm)*	Number of Flowers	Fresh Weight (g)*	Root-to-Shoot Ratio (fresh wt. basis)*
T1	30.44	47.49	0	3.10	0.278
T2	45.55	61.83	7	5.70	0.219
T3	35.20	64.37	1	3.43	0.142
T4	30.88	62.32	0	5.85	0.125
T5	28.72	52.04	2	3.75	0.219
T6	49.45	71.22	3	6.93	0.112
T7	38.27	61.57	1	4.53	0.117
T8	62.38	77.50	5	8.68	0.324
T9	46.43	68.37	0	7.90	0.354
T11	49.37	64.78	0	5.35	0.189
T14	51.72	63.48	2	4.58	0.137
T17	51.11	76.55	1	6.63	0.142
C2	68.49	84.64	0	9.17	0.151
C3	42.08	59.27	0	5.08	0.115
C4	47.03	63.80	3	3.98	0.136

*The dimensions of dead plants were not included in the averaged measurements of the samples.

Based on the measurements shown in Table 18, C2 [redacted] possessed the highest and widest foliage, followed by mixes T8 [redacted] T17 [redacted] and T6 [redacted] The measurements show that the petunia plants typically have a higher spread compared to height. Although these two dimensions appear proportional to each other with an average width to height ratio of 1.5:1. Appendix G contains pictures of the plant performances at the end of the growth trials, separated by media type.

While C2 performed well in terms of foliage, it did not flower during the growth trials. Mix T2 [redacted] performed the best in terms of number of flowers, however only one of its plants flowered. Mixes T8, T6, and C4 [redacted] have the next highest number of flowers, with two plants per mix flowering. Mixes T5 and T17 flowered during the growth trials, although no flowers were visible for the final flower count. Figure 16 demonstrates the spread of flowering along the wall.

	Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12		Column 13	Column 14	Column 15	Column 16	Column 17	Column 18	Column 19	Column 20
Row 4	0	0	0			0	0	0									
Row 5	0	0	0			0	0	0									
Row 6	1	0	1														
Row 7	0	0	2			0	0	0		1	3	0			0	0	0
Row 8	0	0	1			0	0	1		0	0	2			0	0	0
Row 9						2	0	0		0	0	0					
Row 10										0	0	0			0	0	7
Row 11										0	0	0			1	0	1
Row 12															0	0	0

Figure 16. Flower spread and plant mortality (shown in red) for growth trial.

The pattern of fresh weight follows the height and width measurements, with C2 having the highest weight. The next heaviest plants include mixes T8, T9 [redacted] T6, and T17, respectively. For the measurement of the fresh weight, the soilless media and netting had to be completely removed from the roots. Care was taken to prevent any root loss, although some were lost when removing the netting depending on the length and durability of the roots.

In fertile soils, the shoot component increases by weight according to the root, therefore reducing the value of the root-to-shoot ratio [64]. An example of a healthy ratio is shown in Figure 17, where the shoot is greatly developed in comparison to the root system.

Figure 17. Physical demonstration of root-to-shoot ratio for a flourishing plant.

Based on the weight of the separated roots and shoots of the petunias, the ratios were calculated. Smaller ratios are seen for T6, T7, and C3, meaning these mixes have a greater developed shoot relative to roots, although all of the achieved ratios were relatively low.

Regarding plant mortality, only one sample for the mixes T3, T9, and C2 experienced a plant death throughout the growth trial. Due to the randomized pattern of plant mortality, it is unknown if the deaths are a result of poor media performance or any issues with the watering. The C2 plant was noted to not receive water from the hydroponic wall and likely influenced this result. The T9 death was located on the same column as the C2 sample, although the plants placed between them flourished. An example of this is the T2 plant which produced seven flowers during the growth trial. The low performance of C2 and T9 could represent the low water holding capacity of both those mixes for the hydroponic wall growth. As for the T3 sample, it is unknown if it suffered water scarcity similarly to the other two plants. Figure 16 shows the placement of the dead plants.

4.4 Binder Testing Results

The use and transportation of seed pods requires certain metrics to be considered to optimize the selection of binders. Balancing the concentration of binders with their rewetting capabilities and resistance to impacts is essential to provide a viable product.

4.4.1 Preliminary binder results

Results from preliminary binder testing identified [redacted] as the most effective binding agent due to its strong adhesive properties. A detailed description of preliminary binder

results and observations is provided in Appendix D5. All binding agents performed better at higher concentrations relative to the media.

[redacted] binding agents failed to retain the shape of the seed pod and crumbled upon handling. The [redacted] treatment effectively bound the media but resulted in a very hard and brittle seed pod. Preliminary testing also revealed that seed pods made with [redacted] tended to develop an outer "crust" after drying, causing them to become hydrophobic. To mitigate this, [redacted] is combined with the [redacted] treatment following Typha Co.'s recommendation to utilize [redacted] ability. Figure 18 displays the progression of seed pod formation using various binder treatments and molding methods.

Figure 18. Progression of seed pod manufacturing process; [redacted] (left), [redacted] (middle), and [redacted] (right).

As shown in Figure 18, the various binder treatments were all successful at maintaining the physical structure of the seed pods under dry conditions. However, the final seed pod (shown on the right) was the most improved version from the iterative testing processes, with this treatment being selected for further examination. Four treatments of various [redacted] concentrations were combined with a Typha-based media to form the seed pods for rewetting capacity and impact resistance testing. The four treatments are summarized in Table 19.

Table 19. Seed pod binder treatments.

[redacted]

With the use of the netted cups as moulds, the dimensions of the seed pods fit within the 40-60 mm range for maximum diameter and height. The average diameter of the produced seed pods was 50 mm, and the height measured at 40 mm.

4.4.2 Rewetting Capacity

All four media variations with different [redacted] ratios successfully rehydrated when placed in a shallow tray of water. Both the exterior and interior of the seed pods became visibly saturated and retained additional water weight after a 1-minute irrigation cycle in the hydroponic wall. These results confirm that [redacted] significantly improves the seed pods' rewetting ability. Unlike the seed pods treated with [redacted], no hydrophobic properties were observed as seen in the preliminary trials.

4.4.3 Impact Resistance Testing

Binder treatments BT2 and BT4 significantly outperformed BT1 and BT3 in the impact resistance tests. Seed pods treated with BT2 withstood the maximum drop height of 7 feet before failure. In contrast, BT1 performed the worst, failing at a drop height of 1 foot. These results suggest that seed pods with a [redacted] composition lack sufficient binding strength to endure impacts experienced during transportation. The success of BT2 and BT4 indicates that a binder composition between [redacted] is optimal for maintaining seed pod integrity upon impact. The complete impact resistance test data is provided in Appendix D6.

4.5 Manufacturing Procedure

As per communications with Typha Co., the desired manufacturing process of the seed pods would integrate the use of a commercial bale buster commonly used in greenhouse flower production. The specific model number for this product, available to Typha Co. for use from a local nursery, is shown in Figure 19

Figure 19. Logitec Plus – Big Bale Dosage Bunker DB40 [65].

This equipment would mechanically process a bale of Typha growing media with the soil amendments and binding agents, ensuring a consistent formulation of the soilless substrate. The machine would then dispense the substrate into seed pod molds along a conveyor belt, which could then be manually or mechanically compressed to ensure the pods maintain their shape. This modular assembly line will enable flexibility for Typha Co. to operate a partial or fully automated seed pod manufacturing process, aligning for an economic and scalable solution. By automating key stages of production, Typha Co. can achieve efficient and cost-effective manufacturing while maintaining consistency and quality in the final seed pods. Notably, this system can be adapted to meet varying production demands, allowing for future expansion and upgrades of the operation as the market grows.

4.6 Results Summary

Based on the technical specification, germination and growth trials results, the best performing media in terms of properties and plant success are shown in Table 19.

Table 19. Results summary for best performance.

Assessment Methods	Best Performing Media	2nd Best Performing Media	3rd Best Performing Media	4th Best Performing Media
Technical Specifications	T14	T2	T8	T11
Germination Trials	C2, C3	T3, T4, T5, T6, T14, T17	-	-
Foliage Spread	C2	T8	T17	T6
Number of Flowers	T2	T8	T6, C4	T5, T14
Fresh Weight	C2	T8	T9	T6
Root-to-Shoot ratio	T6	T7	C3	T4

The summary shown in Table 19 demonstrates that mixes T2 [redacted] T8 [redacted] and T6 [redacted] remain consistently within the top four best performing media. This demonstrates the potential of [redacted], which is present in all these mixes, for its use in seed pods. T14 [redacted] is another potential mix which performed well in the technical specifications, germination, and number of flowers. This suggests that the [redacted] mix can also be a promising alternative. One technical specification where [redacted] passed, contrary to [redacted], was the C:N ratio. This could indicate that integrating [redacted] into the mix could aid to achieve a desirable C:N ratio. [redacted]. However, testing their concurrent behaviour could prove beneficial to improve the Typha-based media.

For the binder selection, the [redacted] performed better in the drop test and hydration cycle tests than the other considered concentrations. Additionally, the dimension requirement for the production of seed pods fell within the specified criteria with a height of 40 mm and maximum diameter of 50 mm. These dimensions could easily be modified according to the dimensions of the mold.

The suggested manufacturing process would allow for the scalability of the commercial production of seed pods. Industrial equipment already in use in the greenhouse industry would aid in the seamless integration of the process.

5 SUSTAINABILTIY

The Triple Bottom Line (TBL) framework helps organizations balance financial viability, social responsibility, and environmental impact in their operations. To evaluate the sustainability of this approach, five elements from the Green Project Management (GPM) model were selected (see Table 20) [66]. These elements assess the proposed solution's environmental, social, and economic impacts, ensuring a comprehensive approach to sustainability.

Table 20. GPM Model.

Impact		Description of situation (Cause)	Potential Sustainability Impact	Impact Score	Proposed Response	New Score	Change
People Impacts	Protection for Indigenous Peoples	Lake Winnipeg is a vital food source for many Indigenous communities. The overgrowth of Typha in these waters can reduce biodiversity and increase competition for resources among aquatic species, potentially affecting fish populations that Indigenous groups rely on [67].	If the fish populations are impacted, that eliminates a food and economic resource for these indigenous communities.	1	Harvesting Typha from Lake Winnipeg would help mitigate the negative impacts of its overgrowth, promoting a healthier ecosystem and improving biodiversity.	4	3
Planet Impacts	GHG Emissions	Current seed pod manufacturers use peat in their products. Peat mining has negative effects on the environment as it releases large amounts of carbon emissions back into the atmosphere [68].	Peat is a natural carbon sequestered, and thus, when harvesting it, it releases the carbon back into the atmosphere, con tributing to climate change [68].	1	Typha Co. is committed to producing a peat-free seed pod by replacing the bulk of the peat with Typha biomass.	4	3
	Air and Water Quality	Peat is widely harvested for horticulture and fuel, but its extraction has significant environmental consequences. Peat mining depletes wetlands, disrupts water retention, and releases stored carbon into the atmosphere [68].	Peat extraction destroys wetlands that are vital to local ecosystems and disrupts natural water regulation. It also contributes to climate change by releasing stored carbon into the atmosphere [68].	1	Typha Co. is committed to producing a peat-free seed pod by replacing the bulk of the peat with Typha biomass, offering a sustainable alternative in a market currently dominated by peat-based products.	4	3

Impact		Description of situation (Cause)	Potential Sustainability Impact	Impact Score	Proposed Response	New Score	Change
Prosperity Impact	Flexibility/Optionality	This innovation enhances flexibility by adapting to environmental challenges and increasing material availability. It also improves optionality by providing a sustainable alternative to peat, ensuring multiple solutions for growers and manufacturers.	By offering a peat-free seed pod, the project reduces reliance on non-renewable resources, lowers carbon emissions, and supports long-term environmental sustainability.	1	Manufacturing a peat-free seed pod increases flexibility by adapting to environmental concerns and reducing dependence on peat. It also enhances optionality by providing a sustainable alternative that supports multiple applications and market needs.	4	3
	Local Economic Impact	The cultivation of Typha at Grant Lake provides a local source of biomass, supporting regional resource management and reducing dependency on external materials.	Expanding Typha cultivation for peat-free seed pods can create jobs, stimulate the local economy, and promote sustainable industry growth while preserving natural wetlands.	2	Expanding the Typha cultivation project at Grant Lake would create additional jobs, boost local economic activity, and further support sustainable regional development.	5	3

6 DESIGN LIMITATIONS

External factors influenced the development of the project and contributed to some changes in the project. This affected some of the expected deliverables and timeline.

6.1 Elimination of Media for Growth Trials

The germination of the petunias provided less seedlings than required for the growth trials. This resulted in the elimination of [redacted] mixes due to lack of germinated petunias. Removing these mixes allowed for the use of four replicates of all the other chosen mixes in the hydroponic wall, for a total of 60 seedlings.

The choice to eliminate the [redacted] mixes was a result of their performance in the Chinese cabbage seeds trials, however other mixes also did not perform well. Based on the spread of the other mixes with [redacted] the [redacted] was discarded, excluding the mixes T14 and T17 which demonstrated germination. In the phytotoxicity test, the mixes with [redacted] showed the best growth in the three-day period. This data does show that other [redacted] mixes would have likely been a viable option for the following tests and trial.

The timeline of the project restricted the consideration for re-including the [redacted] mixes into the testing phase.

6.2 Hydroponic Wall Use

The Harvest Today hydroponic wall in the University of Manitoba's Grain Storage Building was selected for use in this project based on its ease of accessibility and proven ability to sustain floriculture growth [20]. Several limitations arose from its use. Firstly, the wall was unavailable to use due to controller issues and delayed the project timeline. This resulted in the growth trials not being complete by the time that testing was needed. Thus, the testing samples were chosen prematurely and might not reflect the final results from the growth trials. However, the tested media represented a range of different compositions, and this will inform Typha Co. of the best performing soil amendments for germination and growth. Additionally, the multiple unused slots in the wall could result in the evaporation of the nutrient solution, as well as water exiting the system and accumulating at the front of the wall. A combination of cups and trays helped limit this and hold the exiting water. This water loss required the water tank to be filled approximately every three days.

Lastly, the hydroponic wall is located in a large open room where temperature and humidity levels cannot be controlled consistently. This was sub-optimal for plant growth and for the assessment of their environment.

6.3 Transplantation

The petunia seedlings were transplanted from their peat mix to the Typha-based mixes and controls. Due to the fragility of the roots and small size of the netted cups, some peat mix remained into the cups for the growth trial. This results in the mixes used for the growth trial not being entirely composed of the selected Typha media. The effect of the peat in this trial is unknown as all plants had this component and comparison was not possible.

6.4 Testing and Budget

External testing was selected for most of the chemical tests required for the soilless media. This will provide Typha Co. with more reliable results. However, due to budget constraints, only four mixes were sent to be tested by the external lab. The range of mixes sent to A&L laboratory should generally represent the selected variety of media, but this limits the result as only a small quantity of the used media was tested for their properties. The nitrogen immobilization test was not performed according to the procedure and resulted in invalid results. As nitrates can degrade over time, the late processing negatively impacted the results in an immeasurable amount. With the Flow Injection Analyzer being inaccessible for use by students, its results depend upon the schedule of lab technicians. The processing was incomplete for almost a week after the sample's preparation, affecting the results and delayed their return.

7 RECOMMENDATIONS

The design involved the testing of different Typha-based media using varying soil amendments in germination and growth trials. The properties of the media were assessed based on the several technical specifications. Different binders were also tested to determine the feasibility of seed pod manufacturing. For all these steps there is the potential for further testing and improvement to provide Typha Co. with a competitive seed pod design with a cost-effective manufacturing process.

7.1 Recommendations for Germination and Growth Trials

The germination and growth trials are a large component of this project. Their results allow for a better understanding of the behaviour of the Typha-based media. External constraints impacted the trials, especially for the growth of the plants in the hydroponic wall. The following recommendations suggest improvements for these trials.

7.1.1 Eliminate the presence of peat in growth trials

Transplanting the seedlings to the hydroponic wall left some of the peat mixture surrounding the roots. This implies that the final results for the growth trials cannot be entirely associated with the performance of the Typha-based media. Removing a larger quantity of the peat media while avoiding damaging the seedling's roots would be beneficial to assess the behaviour of the media.

7.1.2 Perform growth trials in a controlled environment

The location of the hydroponic wall in the Grain Storage Building on the University of Manitoba Fort Garry campus left many external factors influence the results of the growth trials. With temperature and relative humidity measurements being important components for monitoring growth conditions, having the trials being controlled would aid in isolating the performance of the plants due to the media. This can be done by either implementing a closed environment on the present hydroponic wall or using the hydroponic wall in the Sustainability in Action Facility's greenhouse.

7.1.3 Ensure sufficient seedlings for growth trials

To prevent any limitations for the growth trials, ensure that excess seeds are planted and germinated, assuming a lower germination rate than that of the supplier's information.

Additionally, ensure that the clay seed coating is fully dissolved (in the case of petunia flowers) through gentle misting, to avoid the migration of seeds which reduces the seedling viability. If necessary, acquire plant plugs from a local supplier to ensure the ideal quantity and growth consistency while limiting plant shock caused by prolonged transportation.

7.2 Recommendations for Testing and Verification Procedures

Testing and verification procedures are essential to ensuring the reliability and accuracy of the experimental results. Standardized testing methods help validate the results of the Typha based media and ensure there is consistency across all testing areas. External variables can impact results, emphasizing the need for thorough verification to ensure accurate and reliable conclusions. The following recommendations outline improvements to increase the testing accuracy and procedural reliability.

7.2.1 Expand testing for [redacted] concentration variability

Due to the findings that [redacted] positively contributed to the Typha based media performance. It is recommended to further test varying concentrations of the two to see if any improvements can be made with different concentrations.

7.2.2 Adjust [redacted]

Testing the Typha-based media with an [redacted] in the soil is necessary, as all current mixes that were tested externally fell out of the required pH range. Adjusting the pH through a [redacted] will provide more information on how the media performs within the optimal pH range for plant growth.

7.2.3 Assess Typha-based media performance across various floricultural species

Testing the Typha based media with different floricultural species is essential for evaluating its versatility and suitability for various plants. Since different species have unique growth requirements, this assessment will provide valuable insights into how well the media supports plant development. Understanding these variations will help refine its composition to accommodate a broader range of plant species.

7.2.4 Utilize third-party testing for technical specifications

It's recommended to have all relevant technical specifications done through a third-party laboratory. This will ensure consistency, accuracy, and unbiased results. It will eliminate any possible variability that could be introduced by in-house testing, as the people involved are not as qualified as the lab technicians. This approach will increase the credibility of the experimental results and ensure all tests are done in the same environment.

7.3 Recommendations for Seed Pod Binders and Manufacturing

The selection and use of sustainable binders in addition to the proposed manufacturing process used in the production of Typha-based germination pods was the first step in evaluating the potential of a soilless seed pods. This preliminary exploration provided valuable insights into the effects of soil binders and highlighted the need for further optimization to enhance the performance of the seed pods. Recommendations for future work includes exploring additional options for binding agents, testing further combinations of the binders, and evaluating their effects on plant germination and development.

7.3.1 Explore additional binder combinations

Due to time constraints, binding agents were tested only as isolated treatments during the preliminary binder experiments. While it was observed that adding [redacted] improved its binding and rewetting properties, further study aimed at combining different binding agents is recommended to optimize the effects of the individual materials. By finding an effective combination, the overall performance of the seed pods can be enhanced, potentially improving both their structural integrity and moisture retention capabilities, which are essential for supporting germination and plant growth.

7.3.2 Test the manufacturing process

Seed pods for this study were manufactured by hand, using a single mold. Further research into scalable manufacturing methods is recommended to improve consistency and reduce production time. Potential approaches could include of a bale buster for material processing and binder mixing and designing a mold with slots for multiple seed pods. Further investigation into possible equipment to apply a compression force to the pods within the mold is also required.

7.3.3 Perform germination tests with binding agents

Due to time constraints, a germination test of the Typha-based media with the proposed binding agents was not feasible. To ensure that these materials do not interfere with plant growth, it is recommended that germination trials be conducted. This will provide valuable insight into the compatibility of the binding agents with seed germination and early plant growth, helping to assess their potential for successful application in germination seed pods.

8 CONCLUSION

The development of a Typha-based medium for seed germination pods presents a sustainable alternative to peat-based and other soilless media, addressing the environmental concerns associated with these materials. Utilizing Typha's nutrient-capturing properties, this project aimed to create a nutrient-dense growing media while also mitigating nutrient overloading in Lake Winnipeg. Technical specifications, including water holding capacity, phytotoxicity, and pH, were used to assess the performance of the Typha media. Additionally, substrate mixtures were tested internally and by third-party laboratories based on media performance in the germination and growth trials, to evaluate technical specifications of different treatments. Several metrics, such as foliage spread, number of flowers, and fresh weight, helped identify successful media for the growth trials.

Based on all these trials and tests, mixes T2 [redacted] T8 [redacted] and T6 [redacted] were identified as best performing Typha-based media. The consistent presence of [redacted] distinguishes these amendments for their germination and growth potential for floriculture. The [redacted] mix, T14 [redacted], also demonstrated its success, most notably, in the technical specifications results. Further testing of varying combinations of these amendments would help improve the development of the germination seed pods to reach all the identified technical specifications, as well as fully eliminate the reliance on peat for floricultural use.

The binder treatment BT2 [redacted] demonstrated promising results in both the drop and wet cycle tests. These showed the potential of these binders to perform essential functions for their commercial use and distribution. A manufacturing process for the seed pods was provided to show the potential increase in production of seed pods for a larger-scale distribution.

These results demonstrate improvements compared to the 2024 capstone project and show the potential for the design of germination seed pods using only Typha-based media and sustainable amendments.

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APPENDICES

APPENDIX A: Bill of Materials

Tables A1 and A2 present the bill of materials required for media design and design verification. Items denoted with an asterisk (*) represent purchases made by the team, totaling $ 779.02, which falls within the given budget. The total cost of the project totaled $1,956.90. Items denoted with a double asterisk (**) were provided to the team in small quantities relative to bulk pricing. These items are not included in the subtotal calculation, and bulk pricing is provided in the cost column instead for future reference.

Table A1. Cost breakdown for creating test media.

Item	Manufacturer/ Product Information	Provided By	Cost
****Composted/pasteurized Typha** (15 L)	Typha Co.	Typha Co.	$ 400/tonne
Perlite (3 L)	HJS Wholesale: Product Code: 450-105408 PV	University of Manitoba Plant Science Department	$ 35.45
****Biochar pellets** (1.5 L)	Carbon Lock Tech	Typha Co.	$ 600/tonne
****Pine fiber** (3 L)	HydraFiber: Ez Blend	Typha Co.	$ 17.50/2.3 ft^3 bale
***Molasses** (15 oz)	Plantation™: Blackstrap Unsulphured Molasses	Amazon	$ 16.45
Agar	Fisher BioReagents: BP1423-500	University of Manitoba	N/A
***Whole brown flaxseeds** (1.095 kg)	Bulk Barn Foods Ltd.: Brown Flax Seeds	Bulk Barn Foods Ltd.	$ 4.48
****Yucca powder** (300 mL)	Black Swallow Living Soils	Typha Co.	$ 12.95/lb
***Peat pods** (36 seed pods)	Jiffy Peat Pellets: 36 pack	Shelmerdine	$ 8.95
***Coir pods** (20 seed pods)	PlantBest Inc.: Coir Pellet Green House Kit 20x42 mm	Shelmerdine	$ 16.79
****Rockwool** (4 cubes)	Grodan	Typha Co.	$ 0.50/cube
***Hammermill screen**	Mill Creek Metalworks: 1/4” screen size	Mill Creek Metalworks	$ 262.50
Subtotal			**$ 346.62**

Table A2. Cost breakdown for verification procedures.

Item	Manufacturer/ Product Information	Provided By	Cost
Petunia seeds (500 pack)	Norseco: 500 pack	Typha Co.	$35.11
***Chinese cabbage seeds** (500 pack)	T&T Seeds: Chinese Cabbage Hybrid Minuet SKU: 1355B	T&T Seeds	$ 16.75
***Plastic cups** (100 cups)	Cogan: Mini Red Disposable Shot Glasses 10 pack	Dollarama	$ 14.60
Grow wall rental (4-month rental)	Harvest Today: Size: The Mega 360 (101.625" x 85.75" x 4")	Harvest Today	$ 800.00
Grow lights rental (4-month rental)	SynceLED/ Model: Raging Kale II	Harvest Today	$ 200.00
***Greenhouse rental** (2-month rental)	Department of Agriculture and Food Science/	University of Manitoba	$ 144.00
2-inch net cups with wide lip rims (200 cups)	Naturezhen: 100 pack	Amazon	$ 19.99
Non-woven biodegradable nursery mesh bags	MOTZU ASIN: B0899XZPQ3 200 pack	Amazon	$ 33.58
Water soluble plant food (1.36 kg)	Miracle Gro: Water Soluble All Purpose Plant Food (20-20-20)	Typha Co.	$ 22.99
Bleach	Clorox: 3.57L UPC: 55500017348	University of Manitoba	$ 7.47
pH down solution	Green Planet SKU: PHD01-DG	Typha Co.	$ 20.99
***Third party media testing** (4 samples)	S8C package (EC, pH, C:N, CEC, and nutrient analysis)	A&L Canada Laboratories Inc	$ 294.80
Subtotal			**$ 1610.28**

APPENDIX B: Flaxseed Mucilage Extraction

The following procedure covers the extraction process of mucilage from whole flaxseeds. The procedure is adapted from methods reviewed by Puligundla and Lim [69].

Materials:

- 250 g whole brown flaxseeds
- 3.5 L water
- Cooking pot
- Stove
- Thermometer
- Fine mesh kitchen strainer

Procedure:

1. Add water to the pot and heat to 80°C.

2. Add seeds to the pot and soak 1.5 hours, stirring periodically.

3. Strain seed husks from solution.

4. Continue heating solution for 30 minutes to reduce water content.

Results:
The 250 g of flaxseeds produced approximately 3 L of mucilage solution. This water-soluble solution has a gel like consistency and is adhesive.

APPENDIX C: Seed pod Manufacturing

[redacted]

Results:

32 pods were produced for seed pod testing. The material composition of replicates is summarized within table C1.

Table C1. Seed pod binder treatments.

[redacted]

APPENDIX D: Design Evaluation and Verification Procedures

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D1. Hydroponic Wall Layout

The following figure represents how the randomized design will be performed on the hydroponic wall. The controls will also be part of the randomized design. Each media mix will be randomized across the wall to address the risk of varying conditions of water and lighting across the wall. The water levels might vary depending on the elevation of the plant in the wall, due to the water dripping down from the top of the wall, as well as the lighting, based on the placement relative to the center of the wall. Therefore, different combinations of water levels and lighting were assessed in the different blocks shown in Figure D1.

Randomized Block Design of Harvest Today Hydroponic Wall

		Column 5	Column 6	Column 7	Column 8	Column 9	Column 10	Column 11	Column 12		Column 13	Column 14	Column 15	Column 16	Column 17	Column 18	Column 19	Column 20	
	Row 4	T8	T3	T11			C3	T14	T1	"Low Light"	"High Water"								
Block 1	Row 5	C2	T2	T9			T6	T17	T5	↑	↓								
	Row 6	C4	T4	T7						↑	↓								
	Row 7	C4	C2	T6			T11	T1	C3		T5	T8	T6			T14	C1	T11	
Block 2	Row 8	T4	T14	T3			T5	T9	T17	"High Light"	T1	T2	C4			T7	T3	C2	**Block 3**
	Row 9						T8	T7	T2		T17	T9	T4						
	Row 10								↓	↓	T1	T3	T14			C4	T17	T2	
	Row 11								↓	↓	T4	T7	C3			T5	C2	T6	**Block 4**
	Row 12								"Low Water"	"Low Light"						T8	T11	T9	

Figure D1. Randomized block design for growth trials in hydroponic wall.

The varying colours in Figure D1 represent the different blocks which will be applied for the growth trials. Meaning that every tested media can be found in each of these blocks. The empty columns found in the middle of the individual blocks represent areas with lower light concentrations and were avoided to provide relative consistency among the rows.

D2. Phytotoxicity (S2.8) Procedure

The following procedure covers the determination of the germination index (GI) for both the control and the Typha samples. The procedure is adapted from Emino and Warman [43] and Warman [53].

Materials:

- 120 mL distilled water
- 9 g of sample (3g per sample)
- Four 250 mL beakers
- Magnetic stirrer
- Centrifuge (ThermoFisher Scientific Centrifuge Model Sorvall Legend RT+)
- Four centrifuge tubes
- Refrigerator
- Four filter papers (Sigma-Aldrich Whatman WHA1001090)
- Four 90 mm petri dishes with lids
- Forty Chinese cabbage seeds
- Incubator (KB115 Kb Series Refrigerated Incubator, Binder)
- Calipers

Procedure:

1. The procedure involves the dilution of the sample to a 1:10 (w/v) media:distilled water ratio, using 3 g of media and 30 mL of distilled water per sample.
2. The solution is then placed in a beaker and stirred for 1 hour with a magnetic stirrer. The samples are transferred to a centrifuge tube, with clear labelling. They are left to cool in the refrigerator for one day.
3. For 1 hour the samples are centrifuged at approximately 2000 rpm and filtered. They are returned to the refrigerator until its next use.
4. To prepare the petri dishes, a filter paper is placed at the bottom of the dish, with 10 seeds placed upon the filter paper. 5 mL of the diluted media is added per dish, ensure a relative consistent spread for the moisture.
5. Another petri dish is prepared using the previous method although only distilled water is used to moisten the filter paper; this sample will act as a control.
6. The petri dishes are then covered to prevent evaporation, and placed in a dark incubator to germinate at 20±2°C. After 72 hours the number of germinated seeds and the elongation of the roots are counted and measured.

Equations:

The following equations are derived from Zucconi et al. [70] and involve the determination of the germination index based on the phytotoxicity test found in section 3.1.1.

$$RSG = \frac{SG_{media}}{SG_{control}} \cdot 100\%$$

Where RSG is the relative seed germination, SG_{media} is the number of germinated seeds in diluted media, and $SG_{control}$ is the number of germinated seeds in control.

$$RRG = \frac{RL_{media}}{RL_{control}} \cdot 100\%$$

Where RRG is the relative root growth, RL_{media} is the mean root length in media, and $RL_{control}$ is the mean root length in control.

Which gives the germination index (GI) equation:

$$GI = \frac{RSG \cdot RRG}{100\%}$$

Results:

For this test, the measurements for the mean root length (RL) included both the root and the stem growing from the germinated seed. To improve consistency, this was done for all seedlings in this test.

Table D1. Phytotoxicity (S2.8) test measurements and results.

Media Number	Number of germinated seeds (SG_{media} and $SG_{control}$)	Relative seed germination (RSG)	Mean root length (RL_{media} and $RL_{control}$)	Relative root growth (RRG)	GI (%)
T1	28	96.6	30.3	177.6	171.5
T2	27	93.1	18.4	107.9	100.4
T3	29	100	29.1	170.6	170.6
T4	29	100	27.7	162.2	162.2
T5	29	100	28.5	166.9	166.9
T6	27	93.1	29.7	173.7	161.7
T7	27	93.1	31.9	186.5	173.6
T8	30	103.4	30.0	175.6	181.6
T9	29	100	29.8	174.3	174.3
T11	27	93.1	34.7	203.3	189.2
T14	30	103.4	34.0	198.7	205.6
T17	29	100	39.6	231.7	231.7
C2	29	100	22.0	128.8	128.8
DI (control)	29	-	17.1	-	-

Sample calculation for T1:

$$RSG = \frac{SG_{media}}{SG_{control}} \cdot 100\% = \frac{28}{29} \cdot 100\% = 96.6$$

$$RRG = \frac{RL_{media}}{RL_{control}} \cdot 100\% = \frac{30.3}{17.1} \cdot 100\% = 177.6$$

$$GI = \frac{RSG \cdot RRG}{100\%} = \frac{96.6 \cdot 177.6}{100\%} = 171.5\%$$

D3. Water holding capacity (S1.1), Total Porosity (S2.4) & Air-Filled Porosity (S2.5)

Procedure

This procedure is taken from the British Columbia Ministry of Agriculture Factsheet for media aeration [51].

Materials:

- Container (allows drainage at its bottom)
- Stopper or plug (seals the drainage hole(s) in container)
- Graduated cylinder
- Pan (collects the water from the drainage container

Procedure:

1. To determine the water holding capacity, total porosity, and air-filled porosity, the drainage hole(s) of the container is first sealed.
2. The container can then be filled with water, this volume needs to be measured and recorded as "container volume".
3. The container is emptied and dried, then filled with the soilless media.
4. The media is slowly saturated by gradually pouring water on its surface, until the surface shines. This can take more than an hour. The added volume of water is recorded as the "total pore volume".
5. Once that saturation is reached, the container is placed inside the pan and the seal is removed to allow for the free water to exit the media. The amount of water which has drained from the media is measured and recorded as "aeration pore volume".

Equations:

The following equations can then be used to calculate the water holding capacity, total porosity, and air-filled porosity:

$$Water\ holding\ capacity\ (\%) = total\ porosity - air\ filled\ porosity$$

$$Total\ porosity\ (\%) = \frac{total\ pore\ volume}{container\ volume} \times 100\%$$

$$Air\ filled\ porosity\ (\%) = \frac{aeration\ pore\ volume}{container\ volume} \times 100\%$$

Results:

Table D2. Water holding capacity (S1.1), Total Porosity (S2.4) & Air-Filled Porosity (S2.5) test measurements and results.

Media	Container Volume (mL)	Total Pore Volume (mL)	Aeration Pore Volume (mL)	Water Holding Capacity (%)	Total Porosity (%)	Air-Filled Porosity (%)
T2	191	113	27.0	45.3	59.16	14.14
T8	191	111	32.5	41.10	58.12	17.02
T11	191	111	44.5	34.82	58.12	23.30
T14	191	112	19.0	48.69	58.64	9.95

Sample Calculations for T2:

$$Water\ holding\ capacity\ (\%) = total\ porosity - air\ filled\ porosity$$

$$= 59.16\% - 14.14\% = 45.3\%$$

$$Total\ porosity\ (\%) = \frac{total\ pore\ volume}{container\ volume} \times 100\% = \frac{113\ mL}{191\ mL} \times 100\% = 59.16\%$$

$$Air\ filled\ porosity\ (\%) = \frac{aeration\ pore\ volume}{container\ volume} \times 100\% = \frac{27.0\ mL}{191\ mL} \times 100\% = 14.14\%$$

D4. Nitrogen Immobilization (S1.2) Procedure

This procedure is adapted from Dombrowsky [52] and the 2024 capstone report [20]. The procedure describes the process to test only one mix. Therefore, depending on the number of mixtures, the procedure will be repeated based on that number.

Materials:

- One seedling tray with drainage holes with minimum 4 cells with a volume of 100mL each
- 400 mL of media (100 mL per cell)
- Rack (to allow for drainage)
- Bin (to hold volume of draining liquid)
- 800 mL of deionized water
- 800 mL of potassium nitrate (KNO3) solution (0.54 g of potassium nitrate/1 L of water)
- Four filter papers (No. 1 Qualitative Paper, Whatman)
- Incubator (KB115 Kb Series Refrigerated Incubator, Binder)
- Four 400 mL beakers
- Stirring rod
- Two funnels
- Four 0.45-micron syringe filters (diameter: 25mm)
- Four syringes (5-10 mL)
- Four 10 mL glass collection vials
- Parafilm
- Flow Injection Analyzer for NO3-N concentration (ASX-410 XYZ AutoSampler, Lachat Instruments)

Procedure:

1. Place 100 mL of moist media into the 4-cell seedling tray, then tap the base to ensure compaction and preventing large air gaps to form.
2. Rest the tray on the rack over the bin which will collect drained liquid from the mixture.
3. Slowly pour 100 mL of deionized water over each cell. Let drain for 30 minutes.
4. Slowly pour 100mL of the KNO_3 solution over each cell. Let drain for 30 minutes.
5. Slowly pour 100mL of the KNO_3 solution over each cell. Let drain for 15 minutes.
6. Give a sharp vertical to the tray to remove excess liquid in the cells. Let drain for 5 minutes.
7. Transfer two of the cell's contents into two different beakers, add 100 mL of deionized water to each beaker. Mix with a stirring rod to achieve a slurry mixture. Let sit for 5 minutes.

8. The individual solutions are then poured over a funnel with filter paper and allowed to drain in another beaker, removing the larger particles.
9. Using a syringe, collect approximately 10 mL of the solution, then attach the 0.45-micron syringe filter to dispense the contents into a glass collection vial. Cover the vial with Parafilm. Repeat this step for the other solution.
10. Measure the NO_3-N concentration of the resulting solution with the Flow Injection Analyzer. This will give the $[NO_3 - N]_{Day\ 0}$ value.
11. The remaining two cells are placed in an incubator at 21°C for four days. After this period, steps 7-10 are repeated, giving the $[NO_3 - N]_{Day\ 4}$value.
12. The NDI calculation can then be done using the equation shown below.

Equations:

The following equation will determine the NDI of the media based on the day zero and day 4 readings:

$$NDI = \frac{[NO_3 - N]_{Day\ 4}}{[NO_3 - N]_{Day\ 0}}$$

The $[NO_3 - N]_{Day\ 0}$ represents the readings taken by the Flow Injection Analyzer on the first day of testing, while $[NO_3 - N]_{Day\ 4}$ is the reading after the fourth day.

Results:

Table D3. Nitrogen immobilization (S1.2) test measurements and results.

Media	$[NO_3 - N]_{Day\ 0}$	$[NO_3 - N]_{Day\ 4}$	NDI (Nitrogen Drawdown Index)
T2	21.0	3.63	**0.173**
T8	21.7	0.82	**0.038**
T11	20.5	1.065	**0.052**
T14	20.95	0.835	**0.040**

The results consist of the average of the $[NO_3 - N]_{Day\ 0}$ and $[NO_3 - N]_{Day\ 4}$ readings for the two replicates done for each mix.

Sample Calculations for T2:

$$NDI = \frac{[NO_3 - N]_{Day\ 4}}{[NO_3 - N]_{Day\ 0}} = \frac{3.63}{21.0} = 0.173$$

D5. Preliminary Binder Testing

Preliminary binder testing consisted of apply varying amounts of binding agents to Typha-based media. The observations of test treatments are summarized with table D4.

Table D4. Preliminary binder observations.

D6. Seed Pod Drop Test Procedure

Materials:

- Seed pods
- Tape measure
- Tape
- Marker

Procedure:

1. Use tape and marker to mark drop heights on a wall.
2. Drop seed pod at increasing elevations until failure. Failure is defined as the seed pod becoming fractured upon impact. An example of a failed impact test is shown in Figure D2
3. Determine the maximum drop height for each seed pod.

Figure D2. Seed pod and fractured portion after a failed impact test.

Results:

Impact test results are summarized within Table D5. Pods with [redacted] composition performed very poorly against the pods with [redacted] concentrations. BT2 [redacted] achieved the maximum drop height of 84 inches.

Table D5. Impact test results.

Drop Height (inches)	Binder Treatment			
	BT1	BT2	BT3	BT4
6	P	P	P	P
12	F	P	P	P
16	-	P	P	P
24	-	P	P	P
30	-	P	F	P

Drop Height (inches)	Binder Treatment			
	BT1	BT2	BT3	BT4
36	-	P	-	P
48	-	P	-	P
54	-	P	-	P
60	-	P	-	P
66	-	P	-	P
72	-	P	-	P
78	-	P	-	P
84	-	P	-	F

APPENDIX E: Technical Specifications Result Ranking

To assess the best performing media from the tested Typha-based mixes, they will be ranked according to their performance. All results which pass the Pass/Fail Criteria will have the maximum allotted points. In the occurrence that the results do not fall within the acceptable range, the best performing result will have the highest score, with a decreasing score for each subsequent result. The primary specifications (S1.1, S1.2, and S1.3) will have a heavier weight associated with their results as they are the main concern for the performance of the media.

Table E1. Technical specification ranking for Typha-based media.

Spec.	Description	Pass/Fail Criteria	Weight	Ranking (Weight x Points*)			
				T2	T8	T11	T14
S1.1	Water Holding Capacity (%)	62-90	2	6	4	2	8
S1.2	Nitrogen Immobilization	NDI>0.79	2	-	-	-	-
S1.3	pH	5.5-6.5	2	2	6	4	8
S2.1	Electrical Conductivity/Soluble Salts (mS/cm)	0.7-3.5	1	4	4	4	4
S2.2	Soil Respiration/Stability (mg CO_2/g VS/day)	<4	1	4	4	4	4
S2.3	Bulk Density (g/cm^3)	0.1-0.2	1	4	3	1	2
S2.4	Total Porosity (%)	71-95	1	4	2	2	3
S2.5	Air-Filled Porosity (%)	10-31	1	4	4	4	3
S2.6	Carbon-to-Nitrogen Ratio (C:N ratio)	20-35:1	1	2	3	4	4
S2.7	Cation Exchange Capacity (meq/100g)	90-140 meq/100g	1	4	2	1	3
S2.8	Phytotoxicity (%GI)	>80% GI	1	1	2	3	4
		Total Points		**35**	**34**	**29**	**43**

*Best performing media = 4 points, 2nd best performing media = 3 points, 3rd best performing media = 2 points, 4th best performing media = 1 point.

The results for the nitrogen immobilization (S1.2) were excluded due to their invalidity. Based on this ranking, mix T14 performed the best, followed by mix T2 and T8.

APPENDIX F: A&L Canada Laboratories Inc. Results.

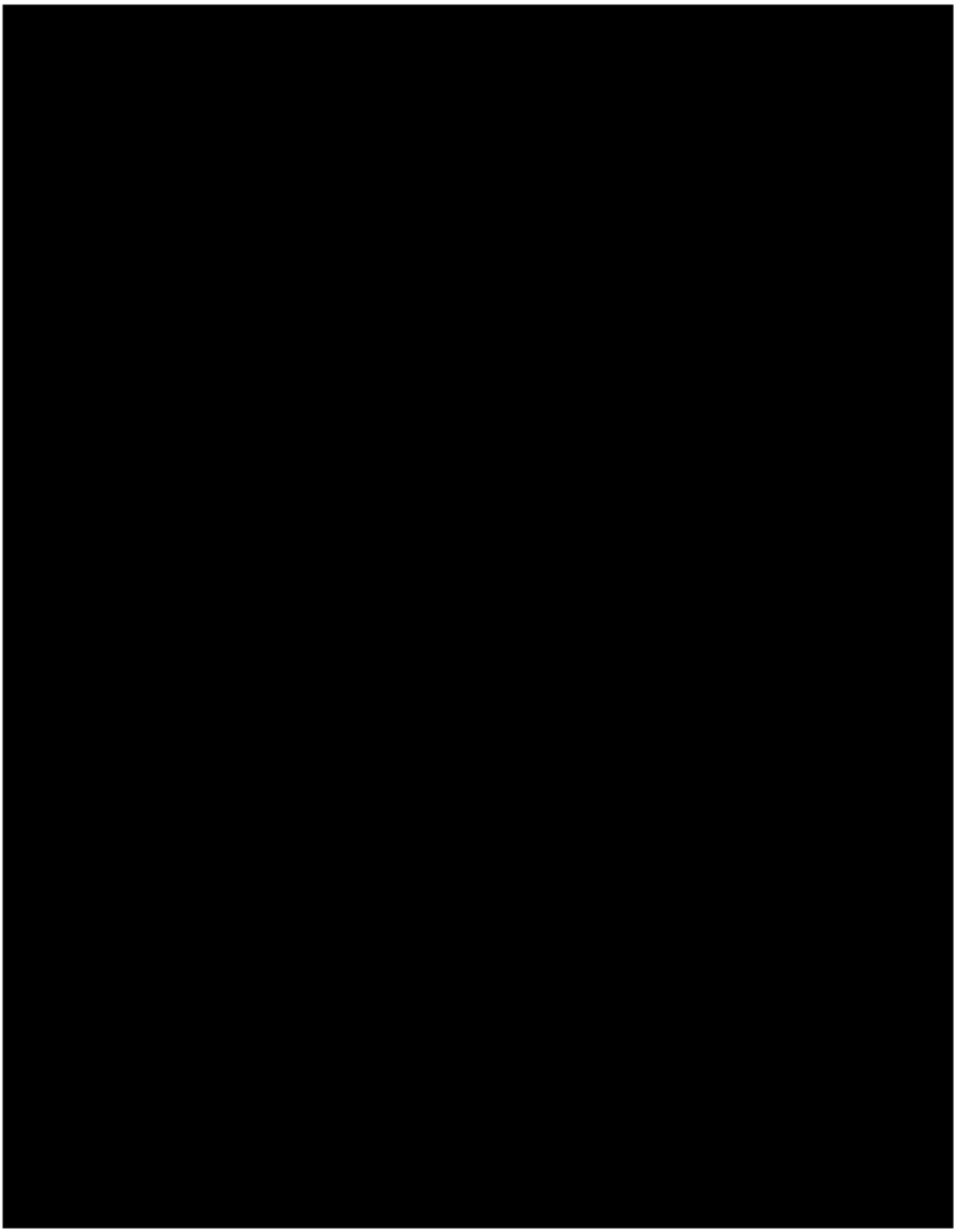

Figure F1. Soil Respiration/Stability (S2.2) test result provided by Typha Co.

Figure F2. T2 [redacted]) mix results for pH (S1.3), Electrical Conductivity/Soluble Salt (S2.1), C:N Ratio (S2.6), and Cation Exchange Capacity (CEC) (S2.7).

Figure F3. T8 mix results for pH (S1.3), Electrical Conductivity/Soluble Salt (S2.1), C:N Ratio (S2.6), and Cation Exchange Capacity (CEC) (S2.7).

Figure F4. T11 mix results for pH (S1.3), Electrical Conductivity/Soluble Salt (S2.1), C:N Ratio (S2.6), and Cation Exchange Capacity (CEC) (S2.7).

Figure F5. T14 mix results for pH (S1.3), Electrical Conductivity/Soluble Salt (S2.1), C:N Ratio (S2.6), and Cation Exchange Capacity (CEC) (S2.7).

Figure F6. Results for all mixes (T2, T8, T11, T14) for Bulk Density (S2.3) and C:N Ratio (S2.6).

APPENDIX G: Growth Trial Results

Figure G1. Growth Trial Results for T1.

Figure G2. Growth Trial Results for T2.

Figure G3. Growth Trial Results for T3.

Figure G4. Growth Trial Results for T4.

Figure G5. Growth Trial Results for T5.

Figure G6. Growth Trial Results for T6.

Figure G7. Growth Trial Results for T7.

Figure G8. Growth Trial Results for T8.

Figure G9. Growth Trial Results for T9

Figure G10. Growth Trial Results for T11.

Figure G11. Growth Trial Results for T14.

Figure G12. Growth Trial Results for T17.

Figure G13. Growth Trial Results for C1.

Figure G14. Growth Trial Results for C2.

Figure G15. Growth Trial Results for C3.