Evaluation of natural and synthetic substrates for use in aeroponic systems

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ABSTRACT

Aeroponic cultivation has become a very popular method of agricultural production. A synthetic material, rock wool is used widely as a growth medium. This research investigated cattail block production and compared its suitability as an alternative to rock wool based on the physical and chemical properties of substrates. The usefulness of cattail blocks for growing three plant types [arugula (*Eruca sativa*) N=18, lettuce *(Lactuca sativa)* N=18, and tomato N=21 (*Solanum lycopersicum*)] was compared with rock wool. In addition, the spent cattail block was compared with raw fibre to determine the possibility of further use. Analysis revealed that the germination performance of the cattail block was better than rock wool, and the difference was statistically significant, with $p = 0.00$ for lettuce and tomato. The survivability (%) of arugula, lettuce, and tomato in aeroponics was better for cattail block than rock wool, and the difference was statistically significant ($p<0.05$). However, the fresh weight of plants was better for rock wool after 35 days of growth in the aeroponic system. The difference was not statistically significant for arugula at $p>0.05$, while for lettuce and tomato, the difference was statistically significant at $p<0.05$. The spent cattail block from the aeroponic system showed the possibility of reuse in the automobile and packaging industries. Finally, the cattail block demonstrated its suitability as growing media and would bring environmental benefits to rock wool.

Keywords: aeroponics, growing media, cattail block, rock wool, germination, plant growth.

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DEDICATION

To the people who suffer from hunger around the world.

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1. INTRODUCTION

1.1 General overview

Soil-less culture is a promising method of agriculture for higher yields with less space to meet the demands for food for the continually increasing population (Bennet Brockhagen et al. 2021). In the emerging field of soil-less agriculture, vertical aeroponic systems are prominent for their highly controllable techniques and aesthetics (Karol and Bowen 2016). Aeroponic systems allow the plant root to grow in suitable growing media and distribute macro and micro-nutrients efficiently to the plant roots from a water-nutrient reservoir (French and Roth 2019). The selection of growing media should be based on the criteria for the propagation of seeds, suitable for irrigation methods, and providing constant support to the growing plant and roots.

1.2 Knowledge gaps

Rock wool is a widely used synthetic growing media for soilless systems. The production of one cubic meter of rock wool involves an average of 275 kWh, and 167 kg of CO_2 released into the environment (Dennis et al. 2015). In addition, the chemical waste from the production process, and the waste disposal issues after its use (Pieters et al. 1998) that add 150 m^3 of waste per hectare per year in landfills (Dennis et al. 2015). The goal of this research is to prepare a realistic and convenient substrate for aeroponic systems by determining available resources. Considering the environmental effects of rock wool during production and waste management, this research aims to develop a sustainable and natural growing media from cattail fibre. This research work compared the essential substrate properties as well as plant growth performance for cattail block and rock wool.

Irrigation in aeroponic systems should ensure proper distribution of water–solution to the plant root. An efficient irrigation system provides the ideal amount of water-nutrient solution to

the plant roots and helps to maintain proper aeration in the plant root zone (Schröder and Lieth 2017). This research also aims to investigate the effect of irrigation schedule on plant growth rate. To obtain optimum irrigation schedule for cattail block and rock wool two different irrigation schedule has been studied.

1.3 Objectives

The following objectives were fulfilled by the proposed research:

- Prepare cattail block as substrate from cattail fibre.
  - Compare the necessary physical and chemical properties required for growing media for cattail block with rock wool.
  - Set cattail block and rock wool for germination and transplant the successful germinated plant to the aeroponic system.
  - To investigate the performance of a cattail block and rock wool in aeroponic system with different irrigation scheduling.
  - Analyze the performance of cattail block and rock wool in terms of germination time, survival rate, and plant growth rate.
- Determine the necessary mechanical and chemical properties of used and raw cattail fibre to verify the reusability.

1.4 Thesis outline

The thesis consists of a total of six chapters, inclusive of two manuscript chapters. The first chapter describes the overview, scopes, objectives, and research questions addressed in this thesis. The second chapter provides the literature related to the thesis research. Chapters three and four are designed as manuscripts, where chapter three focuses on evaluating the suitability of cattail fibre as substrate, the operation of the aeroponic system and a comparative analysis of cattail fibre

block and rock wool in the aeroponic system for different irrigation schedules. Chapter four concentrates on cattail fibre extraction and fibre block preparation. The comparison of raw and used cattail fibre properties was analyzed for the reusability of the cattail block. The concluding chapter summarizes the outcome of this research. Finally, chapter six presents the related reference used in this research.

2. LITERATURE REVIEW

2.1 Overview

Agricultural industries provide the necessities for people all around the world, and especially food for the survival of human beings (Ragaveena et al. 2021). Traditional agriculture requires natural resources (light, water, and fertile land). Most agricultural industries involve using large tracts of suitable land, accessible surface water for irrigation, ecosystem resources under certain climatic situations, and necessary nutrient materials (Gaffney et al. 2019; Mishenin et al. 2021). Modern technologies in regular soil-based farming increased the production and yield of crops; nevertheless, agriculture remains extremely dependent on the weather and sometimes becomes vulnerable to disasters (for example, flood). In such cases, growers cannot meet their target production. To ensure production rates, the use of fertilizer, genetically modified crops, and pesticides in the agricultural industry has increased extensively. These activities adversely affect both our health and our ecosystem. High-performance growing technology other than soil-based culture is quickly becoming popular as a modern-day farming activity both in urban and rural areas (Lakhiar et al. 2018). Soilless indoor farming is gaining popularity and expanding for its controllable resources and wide range of technological features from easy to sophisticate and for its higher production rate and compact controlled environment space requirement.

2.2 Food security

Growing foods in a sustainable manner are complicated because of natural constraints. The agriculture and food sectors work hard to maintain the food supply but are sometimes unable to do so. Extensive use of pesticides is now a major concern for food industries. The greatest challenge for the modern world is not only to eliminate hunger and poverty but also to provide clean, fresh, and nutrient-rich foods. The world population is predicted to reach 9.75 billion by 2050, which

means that agricultural industries need to double their food production from the current level (FAO 2017; Ragaveena et al. 2021). In 2020, between 720 and 811 million people suffered from hunger, in other words, more than 10% of the world's population (The World Bank 2022). The production of adequate food for consumption, the assurance of food stocks and the socioeconomic accessibility to food for all people (Mishenin et al. 2021), are challenges of agriculture worldwide. Urbanization and population increase demand increased food production using the available land (Ragaveena et al. 2021). Modernization of the current agricultural sector with up-to-date technologies could eliminate extreme food insecurity. Therefore, maximizing food production per unit area of farmland using smart technologies is getting attention to reach the goal (Ragaveena et al. 2021).

Northern areas of Canada face extremely adverse weather conditions for farming. Traditional agricultural production in severe conditions or extremely negative climates is impossible (Fernandes 2017). In addition, greenhouse farming requires lots of energy to heat the area and create a suitable atmosphere for plants to grow. Therefore, the cost of the traditional cultivation of crops is not a realistic consideration. People living in remote and cold areas often suffer from malnutrition and are often food insecure. Food insecurity can deteriorate diet quality, increase malnutrition, and risk an unhealthy lifestyle (The World Bank 2022). The complicated transportation process to remote areas increases the cost of delivering food. People in Northern Canada can use small-scale production facilities if technology can meet the growing requirements for economic food production. This could address the threat to food security in the North. The combination of modern growing technology and the development of sustainable and consistent food production could address the threat to food security in Northern Canada.

2.3 Sustainable food production

Sustainable food production is necessary as the world population rises and the demand for healthy and consistent quality food increases. The continuously growing demand for food requires exploring new farming methods to increase food production that will survive the regular threats created by nature as well as mankind. Sustainable agriculture aims to provide a steady yield while reducing environmental impact, preserving nature, and addressing the impact of climate change (Gaffney et al. 2019). Sustainable food production plays a vital role in the purchase decision of vegetables, considering the financial, societal, and environmental aspects (Dennis et al. 2015).

Traditional agricultural faces many issues that are completely uncontrollable, and farmers are challenged, to meet production demands especially considering soil infertility, shortage of water, and natural calamity. Environmental factors particularly climatic changes, erosion of soil, destruction of the ecosystem, and reduced water availability are among the major threats for the agriculture industry to provide enough food (Mishenin et al. 2021).

2.4 Soil-based agriculture

Soils are a very important part of our daily life as it supports us in many areas instance, food, clothing, housing etc. (Bumgarner and Hochmuth 2019). Soil is the most abundant growing media used for thousands of years for growing plants; it contains the necessary macro and micro-nutrients for plant growth and, most importantly, allows water to carry the nutrients to the plant roots (French and Roth 2019). Excessive use of land and too much use of fertilizer are responsible for a constant decrease in soil fertility. Apart from this, extreme rainfall and flooding cause run-off and the loss of the fertile top layer of the soil surface in some areas. Many areas suffer from a shortage of water, dry soil, and severe drought. Sometimes soil contains chemicals, pathogens, hazardous matter, or insects, which could contaminate crops (Bumgarner and Hochmuth 2019).

Moreover, soil-borne pathogens, pests, and parasites are another problem for soil dependent cultivation process as they result in crop damage and often a decrease in crop performance. Soils with poor physical properties, poor drainage or low nutrition impact plant quality and growth (Bumgarner and Hochmuth 2019). Conventional agriculture is the prime consumer of water in the US and around the world (Karol and Bowen 2016). Although water shortage is a major problem for growing plants, excessive use of water causes runoff and loss of the nutrient-rich top layer of soil, which in turn causes water pollution by stimulating algae growth in rivers and lakes (Karol and Bowen 2016). Maintaining the freshness of crops during the transport of the product from the field to the consumer is difficult for the growers. Moreover, transportation and time are both costs to be considered. Urban and suburban lands are often not accessible or feasible for agricultural practices (Bumgarner and Hochmuth 2019).

2.5 History of soilless agriculture

The practice of cultivating plants in different soil-less media was started many years ago with the Egyptian people almost 4000 years ago, although their methods and type of plants grown are not clear (Raviv and Lieth 2008). The first use of controlled environment agriculture was growing cucumbers in a transparent stone (mica) during the 1st century (Jensen 1997). El-Kazzaz and El-Kazzaz (2017) refer to the oldest published work on soil-less agriculture was named 'water culture' in the year 1627 (El-Kazzaz and El-Kazzaz 2017). Laboratory techniques for providing nutrients to plants without soil were developed by the Germans in the 1860s (Jensen 1997). Also, El-Kazzaz and El-Kazzaz (2017) described that, the term 'hydroponics' was first acknowledged in 1937 by Gericke to describe the development of crops using a liquid media (El-Kazzaz and El-Kazzaz 2017). During the 1970s, researchers determined comprehensive nutrient solutions, and proper use of the nutrients for suitable growing media, and explored to optimize the resource

materials, for example, the amount of nutrient-water solution (Raviv and Lieth 2008). Soilless cultivation has gained popularity around the world, and researchers are trying to implement this growing method in all types of climatic situations. For instance, NASA recently developed a soil-less system named Veg-01 to grow green foods in the micro gravity atmosphere of space (Fernandes 2017).

2.6 Soilless cultivation

Soilless culture is a new method that could meet the demands for food for the continually increasing population, especially in cities and areas where traditional farming is not feasible. An alternative to the conventional cultivation system is a soil-less growing system where plant roots build in a media other than soil (Lechevallier et al. 2018). Soil-less agriculture focuses on the cultivation of crops (mainly vegetables and herbs) in small or large indoor farms (Storck et al. 2019). It offers the benefit of eliminating the process of disinfecting the soil, thus reducing the use of chemical pesticides and intensive labour (Raviv and Lieth 2008). The process of the traditional cultivation system increases the stress on growers to keep the vegetables fresh during the lengthy processing lead time. Soil-less culture could reduce the extended supply chain lead time for vegetables to reach the consumer from the growing field.

All soilless systems are involved in cultivating plants where roots are not enclosed by a soil media. The water-nutrient solution is supplied in fixed time interval (Karol and Bowen 2016). Soilless cultivation is used for a variety of green vegetables, such as lettuce, kale, mustard, spinach, Swiss chard, and many more (Bumgarner and Hochmuth 2019). It is popular for cultivating herbs such as basil, chives, oregano, thyme, cilantro, and rosemary (Bumgarner and Hochmuth 2019). Fruiting vegetables, for instance, different varieties of tomatoes, cucumbers, peppers, and strawberries are frequently grown in a soil-less environment (Bumgarner and Hochmuth 2019).

2.7 Various soilless cultures

Better understanding of the complex processes of soil-less cultivation in an aeroponic system and the plant–resource–atmosphere conditions is required for establishing the structure (Karol and Bowen 2016). The controlled environment is a very important criterion for soil-less agriculture. The structure should possess an atmosphere of a precise amount of light and heat, proper irrigation facility, available nutrients, and air. Generally, plants are very complex and in soilless culture, the vulnerability of plants increases when they have a limited physical support system. The support system for the plants is provided in different ways, either by the growing media or by modifying the hanging method. Soilless cultivation introduces different techniques such as hydroponic, aquaponic, and aeroponic systems: all are involved in growing plants in a controlled environment.

2.8 Hydroponic culture

Hydroponic comes from the Greek words hydro (water), and ponos (labour): hydroponic is literally “water working” (Fernandes 2017). Hydroponics systems use a water-nutrient solution in a reservoir, where plant roots are submerged for the entire growing cycle (Karol and Bowen 2016). Hydroponic culture uses water very efficiently, needs no pesticides, and eliminates soil-borne pathogens (Ragaveena et al. 2021). Various hydroponic systems are available for cultivating different crops. The principle of a drip hydroponic system is close to traditional cultivation where plants are supported by an inert substrate and the vital nutrient solutions are pumped through the channels to each plant from a reservoir (Fernandes 2017). The nutrient film technique is mainly a constant recirculation of a water-nutrient solution towards an inclined channel of a plant-growing tray (Fernandes 2017). The channels are maintained with a small slope to let the water-nutrient solution flow down the channel from the top to the bottom and return to the tank by gravity

(Bumgarner and Hochmuth 2019). In deep water hydroponic culture, plants are supported by foam or a floating raft directly on the tank of water-nutrient solution (Fernandes 2017). The drawback of hydroponic culture is the accurate selection of growing media (Ragaveena et al. 2021).

2.9 Aquaponic culture

Aquaponics integrates the cultivation of plants and fish in the same system. An incorporated connection between fish and plants retains a stable aquatic atmosphere, but has the least variation in nutrients (AlShrouf 2017). Therefore, aquaponics is a combination of aquaculture and hydroponics. The waste from the fish provides nutrients for the growing plants, and the plants give clean water for the fish (AlShrouf 2017). The fish in the aquaponic environment emit ammonia through their gills and waste (French and Roth 2019). Some naturally occurring bacteria convert the fish waste into nitrates, which becomes plant food (French and Roth 2019). An aquaponic system needs an appropriate ratio of plants to fish to be successful and sustainable (French and Roth 2019). However, an aquaponic culture should be monitored continuously for the ammonia level, so plants and fishes are not lost due to excessive ammonia in the water (Ragaveena et al. 2021).

2.10 Aeroponic culture

The word aeroponic comes from the Greek words aer (air), and ponos (labour); so aeroponic means “air work” or labour (Ragaveena et al. 2021). Aeroponic cultivation involves exposing plant roots in a hanging state to nutrient rich water droplets. The structure allows the plant roots to hang in air so the roots get more oxygen and facilitates faster growing than other systems (Fernandes 2017). The key elements of the aeroponic system are pipes for holding the growing plants and for irrigation, a pump for water circulation, spray nozzles for distributing water-nutrient solution and a timer to regulate the application of nutrient solution from the storage

reservoir to the plants (Ragaveena et al. 2021). The benefit of aeroponic system is growing tuberous vegetables such as potatoes or carrots, as the system allows better root growth (Fernandes 2017). A vertical aeroponic system utilizes space more efficiently than any other farming facility. Aeroponic system reduces water consumption by 98 percent, fertilizer consumption by 60 percent and pesticide use by 100 percent while maximizing crop yields (AlShrouf 2017). An aeroponic system produces healthier and more nutritious plants with more minerals and vitamins (AlShrouf 2017). The aeroponic system is relatively simple and easy to execute, excellent for controllability, and experiences less algal growth over time (Karol and Bowen 2016). The structure could be applied to both small and large-scale production, and the design provides the flexibility to alter the amount of essential elements of agriculture e.g. light, nutrient materials, and water circulation could be changed easily as the requirements of crops differ (Karol and Bowen 2016). The main principles of supplying water-nutrients is by continuous flow drip or spray (Bumgarner and Hochmuth 2019). Some systems use a constant water flow: some tower systems pump the water–nutrient solution to the top of the tower and allow it to drain through the plant roots to the reservoir underneath (Bumgarner and Hochmuth 2019), and others use an intermittent flow rate for the water-nutrient solutions (Bumgarner and Hochmuth 2019). The main advantage of an aeroponic system is the use of a precise amount of water-nutrient solution based on the plant condition (Ragaveena et al. 2021). In general, soil-based agriculture applies two or three times the nutrients needed for the total growing cycle as there is nutrient loss through water runoff. However, excess nutrients cause weed development in the field, requiring extra labour for weed control. In the case of aeroponic system, since nutrients are applied in small amounts several times, all nutrients are utilized by the plants efficiently, and there is no possibility of the development of weed (Ragaveena et al. 2021).

2.11 Vertical aeroponic culture

Vertical aeroponic systems have quite a few advantages over the conventional method of growing. This technique reduces the requirement for large tracts of agricultural land, uses fertilizers, and decreases the consumption of water (Storck et al. 2019). Aeroponic cultivation utilizes land better by cultivating plants vertically in columns at several pockets (Storck et al. 2019), thereby providing more yield per unit area compared to the traditional technique. The reason attention to soil-less cultivation in the field of agriculture over traditional soil cultivation is the simplicity of the controlled circulation of water-nutrient solution through the roots of the plants and less dependence on nature, and above all, better yield (Raviv and Lieth 2008). The consistency in the plant growth rate of the aeroponic systems in different situations reduces the possibility of an unexpected crisis of food shortage due to different calamities that affect the traditional system of growing (Storck et al. 2019). As the vertical aeroponic system are a controlled environment, it is easier to set goals for plant yield and use of resources (Storck et al. 2019). Soil-less farming optimizes the nutrient solutions for growing plants; therefore, more growing cycles per year could be achieved (French and Roth 2019). The automation technologies used in aeroponic system facilitate reduced manual labour, in contrast to conventional field agriculture that requires extensive physical labour (Karol and Bowen 2016). The introduction of light-emitting diode (LED) lights diminishes the dependence on solar systems for energy and heating in the case of aeroponic agriculture. The aeroponic system uses the same water in a small, closed reservoir, thus eliminating the chances of water-nutrient pollution as in conventional agriculture.

Moreover, recycling of water through the soil-less system reduces water consumption by 90% (French and Roth 2019). Indoor vertical arrangements are suitable for small and large facilities as well as the urban environment. As a result, food could be grown in a versatile type of atmosphere, even in extensively cold or hot weather, with or without rain or fertile soil; even the

living room of a house is suitable for vertical farming.

The main disadvantage of an aeroponic system is the need for a backup arrangement and a spare pump, as the plants depend entirely on the sprinkler system for water circulation and nutrition (Ragaveena et al. 2021).

2.12 Growing media

The growing media or substrate is an essential component of soil-less cultivation, as it is used for the total plant growing cycle from germination to harvest. The properties of the substrate material should be suitable for soil-less culture according to plant type, atmospheric conditions, and total arrangement of the growing cycle (Juneau et al. 2006). Growing media used in aeroponic systems provide the plant shoots and roots continuous support throughout the growing cycle. The substrate provides mechanical support to the plant (Storck et al. 2019) and helps the root to absorb the water-nutrient solution during the initial stages of growth. Widely used substrate materials are rockwool, perlite, peat and sand, however, sand and bark show better sustainability (Storck et al. 2019). The substrate must allow roots to get enough water, oxygen, and nutrients for satisfactory plant growth (Juneau et al. 2006), should provide enough storage for water-nutrients for the plant roots, and at the same time should maintain proper aeration (Wallach 2008).

The range of substrate materials is wide and increasing because of continuous research on growing media. Growers generally attempt to trial various types of substrates for their growing operations. They check the suitability of substrate for local and viable materials (Landis et al. 2014). Local natural raw materials become affordable for the growers in terms of cost and availability.

Substrate is generally selected according to the demand of harvesting and the end use performance. Usually, greenhouses use three types of substrates for cultivating plants in the soil-

less systems. The first substrate, used for seed propagation or germination, should be finer in texture and maintain good moisture (Landis et al. 2014). The second substrate, used for root formation, should have a porous structure and excellent aeration properties (Landis et al. 2014). The last substrate, used to transplant the propagated seeds or small plants into larger soil-less system has a coarser structure (Landis et al. 2014).

2.13 Types of growing media

Various raw materials are used to prepare substrates for the soil-less system in horticultural industries for both commercial and noncommercial cultivation. Depending on the source of the raw material, substrate materials are classified mainly as organic such as peat, coconut coir, wood fibre, bark, sawdust, and composted plant waste (Maher et al. 2008); or inorganic such as rock wool, urea-formaldehyde polymer foams, polyester fleece, pumice, and perlite. Some clay materials (vermiculite, and expanded clay) are also used as substrate (Papadopoulos et al. 2008). Sustainable natural substrates used in greenhouses could trim major growing costs by reducing the use of water and nutrients, the impact of soil borne diseases, and improving the consistency and quality of the crop yield (Lechevallier et al. 2018) and most importantly, reducing the stress on the environment during the disposal of residue after each growing cycle. The manufacturing process of substrate materials and their disposal is also an environmental concern (Dennis et al. 2015).

2.14 Rockwool

Rockwool, also called mineral wool, is one of the most extensively used growing media for the industrial soil-less production facilities (Lechevallier et al. 2018). It is used world-wide for seed propagation and complete farming of vegetables such as tomato, cucumber and pepper (Dennis et al. 2015). Rockwool is an inert growing media that provides a suitable atmosphere for

the growth of plant and root structures (Lechevallier et al. 2018). The properties of the growing media such as good water holding capacity, proper aeration, neutral electrical conductivity, water-nutrient capture from irrigation and holding it for roots makes rock wool a popular growing media (Lechevallier et al. 2018). The low water buffer capacity and high pH of rock wool requires regular maintenance during the growth cycle (Lechevallier et al. 2018). A short irrigation scheduling for rock wool substrate is recommended (Lechevallier et al. 2018). This substrate is usually disposed after a single cultivation cycle as landfill waste, which is becoming a threat to the environment (Pieters et al. 1998). Rockwool is neither easily recyclable nor biodegradable (Kennard et al. 2020) and as such is a major concern for the environment not only for the disposal of residue from the green house operation, and the central waste stream from a greenhouse (Dennis et al. 2015), but also from the substrate production facilities due to high processing temperature and chemical waste. Rockwool is manufactured in energy-intensive facilities and processed at temperatures up to 1100˚C to 1600˚C (Kennard et al. 2020; Papadopoulos et al. 2008). The cost and energy required for the production and the waste management problems led greenhouse growers to abandon the use of rockwool (Juneau et al. 2006). The use of environmentally friendly substrate material (such as biodegradable or reusable) could minimize the waste flow from greenhouses (Pieters et al. 1998).

2.15 Perlite

Perlite is a porous and amorphous volcanic rock composed of 70-75% of silicon dioxide (EPA 1995). Although perlite is sterile, the pH is neutral, and it has good aeration properties (Landis et al. 2014), it is not used as an individual substrate material for farming. The porous structure of perlite gives the substrate good drainage and aeration properties when mixed up to 30 percent with another substrate material (Landis et al. 2014). Perlite contains fine dust particles,

which makes it difficult for the worker to prepare and mix with another substrate. These dust particles could also clog the irrigation channels and disrupt the water circulation system (Landis et al. 2014). The preparation process of perlite involves furnace temperatures ranging from 870˚C to 980˚C, and the production facilities emit particulate matter and trace elements into the environment (EPA 1995) causing severe pollution.

2.16 Peat

Peat has been used widely and has gained popularity as a substrate for container growing. Peat is an economically viable component as a soil-less growing media for its excellent growing properties, widespread availability, and flexibility of raw material (Barrett et al. 2016). Peat provides efficient performance with little processing and reduced handling costs (Barrett et al. 2016). There are, however, environmental concerns regarding the use of peat as a growing media because it is generally sourced from non-renewable resources (Juneau et al. 2006). The preparation and extraction process of peat causes reduction in carbon sequestration, damage to natural habitats and causes a decline in the groundwater quality in affected areas (Scott et al. 1993). Increasing market demand leads peat producers to frequently open new peat processing lands, which increase the threat to the natural ecosystem and will contribute to global warming (Daigle and Gautreau-Daigle 1992; Juneau et al. 2006). The peat industries in North America produce over 9 x 10^6 m^3 peat per year (Juneau et al. 2006).

2.17 Coir

Coir is an excellent sustainable organic material for preparing substrate, available in some tropical areas (Landis et al. 2014). Coir shows desirable properties as substrate material such as the water-holding capacity, flexibility, suitable pH for growing crops, cation exchange property and electrical conductivity (Landis et al. 2014). However, the use of coir as substrate could be a

problem for plants as the raw materials contain excess salinity (Nichols 2013) and chloride at a toxic level (Landis et al. 2014). Therefore, coir fibres need to be washed rigorously to get rid of excess saline compounds: sodium (Na) and Potassium (K), and it is necessary to treat coir with calcium nitrate ($Ca(NO_3)_2$) solution to develop available calcium (Ca) for the plants (Lechevallier et al. 2018). The use of coir substrate increases the cost of production as coir needs to be held in a container and requires high irrigation frequency (French and Roth 2019) during the growth cycle. Coir fibre is not available in different parts of the world, so could increase the cost associated with transportation.

Natural fibres are most advantageous over synthetic materials as they are biodegradable, are abundant, not harmful to the environment, and are cost-effective. Various types of natural fibres could be used as substrate raw material to achieve a sustainable quality production facility for a horticulture system. Ancient people are known to have used natural fibres to meet their basic needs of clothing and other essential supplies: for instance, building materials, storage, and accessories such as fishing nets and ropes (Kozlowski et al. 2013). Natural fibres are applied in versatile sectors as engineered products, such as composites in manufacturing industries, automotive fields, aerospace industries, and civil construction sites.

Natural fibres must have some essential properties to be considered for industrial applications, such as fibre structure, flexibility, strength, fineness, and the ability to react with acid or alkali (Hearle and Morton 2008; Klein 2016; Saville 1999; Trotman 1984). Raw material selection for different industrial applications should be made based on the availability of plants, the bulk plantation process of the fibre and the cost of maintenance of the materials for that country or region. The raw materials for a growing media are selected depending on their availability, end-use performance, and cost effectiveness. Several natural fibres have the possibility and good

prospect as a substrate raw material for application in soil-less agriculture. Coir has been established as an efficient growing media in different horticulture areas. Various other natural fibres have been effectively implemented as growing media, for example, transformed cotton fibre waste, wood fibre (Barrett et al. 2016), pine tree substrate, pine bark (Jackson et al. 2009), mineral fibres (Blok and Wever 2008), textile fabric (Storck et al. 2019).

2.18 Water-nutrient solution

In soil-based agriculture, plant roots take up the necessary nutrient compounds dissolved in the water and soil particles (Bumgarner and Hochmuth 2019). In soil-less agriculture, the higher plant yield requires an aqueous nutrient/fertilizer solution (Lakhiar et al. 2018). The inorganic ions of the nutrients play a crucial role in the physiological aspect of plant health: their absence could hamper the plant growth (Taiz and Zeiger 2002). The amount and composition of nutrients required for growth depend on the plants, weather conditions, the method of applying nutrients (Lakhiar et al. 2018).

Generally, plants need seventeen vital inorganic nutrients to maintain their health at an optimum level and provide a considerable yield (Lakhiar et al. 2018) including phosphorus (P), sulfur (S), potassium (K), nitrogen (N), and zinc (Zn) (Lakhiar et al. 2018; Rolot et al. 2002). The nutrients required by plants could be divided into two groups: macronutrients of nitrogen (N), phosphorous (P), potassium (K) usually known as NPK; and micronutrients iron (Fe), copper (Cu), boron (B), magnesium (Mg), zinc (Zn), and molybdenum (Mo) (Grewal et al. 2011). Some nutrients can be obtained by the plants directly from the atmosphere - carbon (C), hydrogen (H) and oxygen (O) (Lakhiar et al. 2018; Ragaveena et al. 2021). Plants cannot survive with a deficit of these nutrient elements, and it is not possible to replace them with supplementary nutrient elements (Lakhiar et al. 2018). In addition, pH level of the water-nutrient solution must be

maintained appropriately (Bumgarner and Hochmuth 2019). Water-nutrient solution is supplied with the different irrigation methods.

2.19 Irrigation

Plants cannot grow without efficient irrigation in both soil-based and soil-less agriculture. Irrigation scheduling is a vital component of soil-less culture as the plant depends wholly on the circulation of the water-nutrient solution through the system zone (Schröder and Lieth 2017). The reservoir must be continuously restocked to maintain an adequate water-nutrient solution (Schröder and Lieth. 2017). An aeroponic system applies less water-nutrient in the form of mist or droplets as the plant roots are sprayed at predetermined intervals (Lakhiar et al. 2018). The process uses a precise droplet size for the exposed roots in the arrangement so the plant can absorb the nutrients efficiently through osmosis (Lakhiar et al. 2018). Water circulation timing depends on the type of growing media used and the needs of the plant roots.

2.20 Issues with soilless agriculture

As a new technology, soil-less agriculture is not flawless. The main disadvantage of soil-less culture is the high energy consumption for light and heat (Storck et al. 2019). As noted above, soil-less cultivation requires a continuous supply of water-nutrient solution with accurate and precise timing and allocation to reach optimal yield (Raviv and Lieth 2008). Soil-less farms may face an entire loss of crop due to the spread of disease, technical issues, power failure (Storck et al. 2019). The compact nature of a vertical aeroponic system eliminates the possibility of cultivating crops like rice, wheat or corn (Storck et al. 2019).

Plant root development is particularly important for immobile nutrients such as P, Mn, and Zn in the traditional (soil) cultivation (Kafkafi 2008). Therefore, it is crucial for the plants in soil-based culture to constantly grow their root system to ensure efficient uptake of water-borne

nutrient from the soil (Kafkafi 2008). Plants cultivated in soil usually have a fine root system that provides easy contact with the water-borne nutrients (Kafkafi 2008). As the development of plant roots is continuous (Bengough et al. 2006), the roots of soil-less container-grown plants are typically very dense (Kafkafi 2008). The higher root density in soil-less cultivation allows to absorbs more oxygen and nutrients per unit volume of root, so the concentration of dissolved oxygen and nutrients in the solution rapidly decreases (Kafkafi 2008) making the plant roots vulnerable to diseases and even death (Kafkafi 2008).

2.21 Conclusion

The agricultural sector faces great challenges with global warming, climate change, water level depletion, and increasing surface water salinity. Lands are constantly being taken for expanding infrastructures to increasing population and industry. Thus, the availability of essential food stock has skyrocketed along with the price of food. The COVID-19 pandemic has shown that food insecurity and a broken supply chain show the necessity of implementing small-scale and self-sufficient cottage industries worldwide. Implementing an aeroponic system would be economically viable, advantageous, and essential for local growers to carry out agricultural activities in rural areas of extreme weather or in urban cities (Lakhiar et al. 2018). The aeroponic system would be the best possible resolution to eradicate food insecurity and would provide green, fresh foods and vegetables (Lakhiar et al. 2018).

Although there is much research done on the implementation of aeroponic systems, more research could be carried out to simplify the automation of aeroponic system, to select growing media based on the plants to be cultivated and the irrigation schedule required, to source natural raw materials for growing media, and to standardize irrigation for different crops and the water/ nutrient ratio depending on crops and growing periods. Proper implementation of the system and

the exact combination of structure, substrate, nutrient, and irrigation could bring a promising outcome from the aeroponic cultivation process. Continuous improvement of the soilless culture could expand the agriculture sector with low-cost automation and simplified techniques.

Soilless culture has advantages not only in sustainable for food production, but also in terms of economy. A comprehensive financial analysis has revealed that the use of soilless agriculture for vegetables can considerably increase profit over the traditional soil-based cultivation (Grafiadellis et al. 2000).

3. Comparative evaluation of natural and synthetic growing media in aeroponic systems

ABSTRACT

Aeroponics or soilless agriculture is ideal for growing vegetables and fruits in cold regions and urban areas. Currently, rock wool, a synthetic material that produces much waste during manufacture and end use, is used in aeroponic systems to initiate growth. The current research investigated an environmentally friendly waste biomass (Cattail) as a growing medium and compared its performance with rock wool. Two irrigation schedules: 3 minutes off/10 seconds on and 6 minutes off/10 seconds on, were investigated to grow arugula (*Eruca sativa*) (N=18), lettuce *(Lactuca sativa)* (N=18), tomato (*Solanum lycopersicum*) (N=21) plants. The germination performance was evaluated using the 'rate of emergence' of sprouted seed, and growth was assessed using plant survivability and weight. It was found that overall, cattail block acted either similar to or better than the currently used rock wool in germination and survivability. However, the average fresh plant weight was better for rock wool after 35 days of growth in aeroponic systems. The current research findings suggest that cattail fibres may be used as a soilless growing media, providing an environmentally friendly alternative to rock wool.

Keywords: substrate, vegetation, properties of growing media, germination, plant growth, irrigation.

INTRODUCTION

According to the Library of Parliament, Ottawa, Canada (2020), "Food insecurity is generally defined as a situation that exists when people lack secure access to sufficient amounts of safe and nutritious food." The people in Northern areas of Canada are at risk of food insecurity (Leblanc-Laurendeau 2019). When the railway, the only land link to Churchill, Manitoba, was damaged by spring flooding in 2017 (MacLean 2018), the town depended on air shipment for food (MacLean 2018), which sent food prices soaring. At the best of times, food is often up to two weeks old by the time it arrives (MacLean 2018). A head of romaine lettuce costs between $5 and $7.50 at the grocery store in Churchill. However, romaine lettuce is sold for $3.50 per item from a hydroponic growing project in Churchill (MacLean 2018).

Weather does not favour agriculture and farming in the northern communities, and even greenhouses are costly. Sustainable indoor growing operations could eliminate the uncertain food supply in the Northern areas of Canada. Soilless culture is becoming popular for its advantages over traditional agriculture because of its dependence on natural resources like agricultural land, sunlight, weather conditions, and nutrient-rich soils (Lei and Engeseth 2021). Soilless culture could be the best way to alleviate food scarcity in Northern Canada (MacLean 2018).

Aeroponic systems are a popular soilless culture widely used in greenhouses (McKeon-Bennett and Hodkinson 2021; Ríos Salazar et al. 2020). In aeroponic systems, all the required water and fertilizer are supplied from an external source. The water and fertilizers are mixed in a predetermined ratio, balanced, and continuously pumped from a reservoir through a distribution network to the aeroponic systems. Since the water-nutrient circulation is carried out intermittently throughout the entire growing cycle, the irrigation scheduling for aeroponics is crucial for plant yields. The irrigation schedule must have intermittent on-off segments that allow the plants to

absorb the water-nutrient solution periodically, allowing sufficient aeration of the roots (Ríos Salazar et al. 2020).

Rock wool is a popular growth media used in aeroponic systems. The production of rockwool requires high-temperature processing. One cubic meter of rockwool production process needs a standard energy 275 kWh and releases 167 kg CO_2 to the atmosphere. In addition, about 150 m^3 of rock wool waste/hectare/year ends up in landfills (Dennis et al. 2015). Peat moss is another popular growing media for soilless culture. More than 9 million m^3 of peat is manufactured by the North American peat industry annually (Daigle and Gautreau-Daigle 1992; Hood and Sopo 2000) primarily for use as a growing media (Juneau et al. 2006). Peat manufacturers are repeatedly harvesting from new peat lands to meet the market demand, ultimately increasing the threat to the ecosystems in that area (Juneau et al. 2006).

Manufacturers of growing media need to focus on the economic and environmental concerns of waste disposal. The growing media production should be an environmentally friendly manufacturing process. The raw material selection should be based on inexpensive, biodegradable, and easily accessible natural materials. The selection of a new substrate material must be consider irrigation methods (Juneau et al. 2006) and various soilless greenhouse production systems.

An efficient substrate must possess a structure which provides a suitable balance of air and water within the structure that can be maintained throughout the growth cycle (Barrett et al. 2016) and allow the plant roots to get an adequate amount of water, oxygen, and nutrients (Juneau et al. 2006). Therefore, the physical properties of bulk density, porosity (total porosity and air-filled porosity) and water-holding capacity are the fundamental properties of growing media that should be evaluated in the selection process.

Bulk density is described as the ratio of the weight of dry substrate to the volume of the substrate (Blok et al. 2008), or the weight per unit volume of the substrate with unit g cm^{-3} (Wallach 2008), as measured by the standard CEN 12580, 1999 (Blok et al. 2008). Bulk density ranges for different growing media from 0.049 to 0.489 g cm^{-3} for rock wool, perlite, polyurethane and clay granules (Blok and Wever 2008).

The total porosity is usually described as a percentage of the total pore volume of the substrate compared to the total volume of the substrate (Blok and Wever 2008). Itis related to the shape, size, and arrangement of the substrate particles (Wallach 2008). For the production of horticulture crops, total porosity is suggested to be 50% to 85% (Bilderback et al. 2005). Total porosity and air porosity, or the volume of pore space in a growing media occupied by air (Troy 2021), are essential for the movement of water-nutrient solutions and for gaseous interactions over the root zone (Troy 2021). Large pores in a growing media maintain air space and assist drainage, while small pores facilitate holding available water (Troy 2021).

Air-filled porosity or airspace is an essential property for root growth in the substrate. Available oxygen for the roots depends on the rate of air exchange within the substrate and atmosphere (Wallach 2008). This is expressed as the volume of material occupied by air as measured by allowing the material to be fully saturated by water and later allowing the water to drain by gravity (Barrett et al. 2016; Bilderback 2008). Standard growing media have an air-filled porosity of 10% to 30% (Wallach 2008).

Important chemical characteristics of an efficient growing media are pH level, electrical conductivity, and availability of nutrient material (Barrett et al. 2016). As pH affects the availability of micronutrients in the growing media (Iersel 2020), and most plants absorb their necessary nutrients within a range of 5.0–5.5 pH (Lucas and Davis 1961), the irrigation water-

nutrient solution should be within the range of 5.2–6.8 (Iersel 2020). Irrigation water-nutrient solution with high alkalinity (high pH) can cause micronutrient deficiencies (Iersel 2020). The electrical conductivity of the water-nutrient solution in a soilless cultivation system is important (Iersel 2020) for the development of plant quality (Dorais et al. 1998). The electrical conductivity for a good growing media ranges within 2.6-5.1 ds m^{-1} (Dorais et al. 1998; Juneau et al. 2006). Plant growth performance depends mainly on the physical properties as well as the chemical characteristics of the substrate in a soilless culture. Hence the measurement of important physical and chemical characterises of the substrate material is required for selecting and using a substrate or growing media for use in aeroponic systems.

This research introduces cattail, a natural and sustainable fibre, as an alternate medium to synthetic rock wool. Biomass cattail fibre possesses excellent mechanical, chemical, and biodegradable properties for application as a growing media. Moreover, cattail plants are known as nutrient absorbers in aquatic environments. Therefore, a cattail substrate block would provide the initial necessary nutrients to plants. After completion of the growth cycle, cattail blocks could be disposed into the soil to be composted or can be reused.

Therefore, this research examines the suitability of cattail fibre block as a growing media by comparing its essential physical and chemical properties to the rock wool. Germination performance and plant growth of a cattail fibre block are evaluated and compared with rock wool in aeroponic systems using different irrigation schedules and determining the optimum irrigation schedule by assessing the performance of cattail substrates with rock wool.

MATERIALS AND METHODOLOGY

3.1 Growing media collection

Cattail block production: Detail description of cattail fibre extraction, fibre processing and cattail block preparation is discussed in Chapter 4.

Rock wool collection: Rock wool was obtained from the Department of Plant Sciences at the University of Manitoba. The rockwool block was cut into 1″ x 1″ cubes to be used as a growing media for seed germination and to transplant the germinated plants into the aeroponic systems.

3.2 Aeroponic system design

An experimental aeroponic system designed for growing plants in soilless culture, was housed in an enclosure made of slotted steel shelving (dimensions: 2.12 m length, 0.60 m width and 2.75 m height). The shelving was enclosed in a double-wall polyethylene sheet to maintain high humidity. The aeroponic system was located in the Soil and Water Engineering Laboratory at the University of Manitoba (U of M). The aeroponic system is comprised of six vertical growing columns made from PVC plastic sewer pipes (4″ x 5′). Each growing column incorporated nineteen (19) openings or pockets in three vertical lines for substrate-plant spacing facing the inner part of the steel enclosure. The plants were held in place inside the pocket with small bamboo skewers inserted into a substrate placed inside the pockets. The roots of the plant hung inside the growing column suspended in air, and a water-nutrient solution was sprinkled down periodically from a reservoir at the top of each column to wet the plant roots. Excess water droplets were collected at the bottom of the column and returned to the main water supply reservoir at the bottom. The reservoir contained the water-nutrient solution consisting of 25-litres water and 175 drops of nutrient solution (Schultz, Premier Tech Home & Garden Inc., United Industries Crop.). A submersible water pump (Barst JR-3000, Jier Electrical Appliances Co., Ltd, US) having a flow

rate of 1514 litres per hour was used for the total irrigation system with the assistance of the main delivery line and a distribution reservoir placed above the vertical PVC pipes containing the plants.

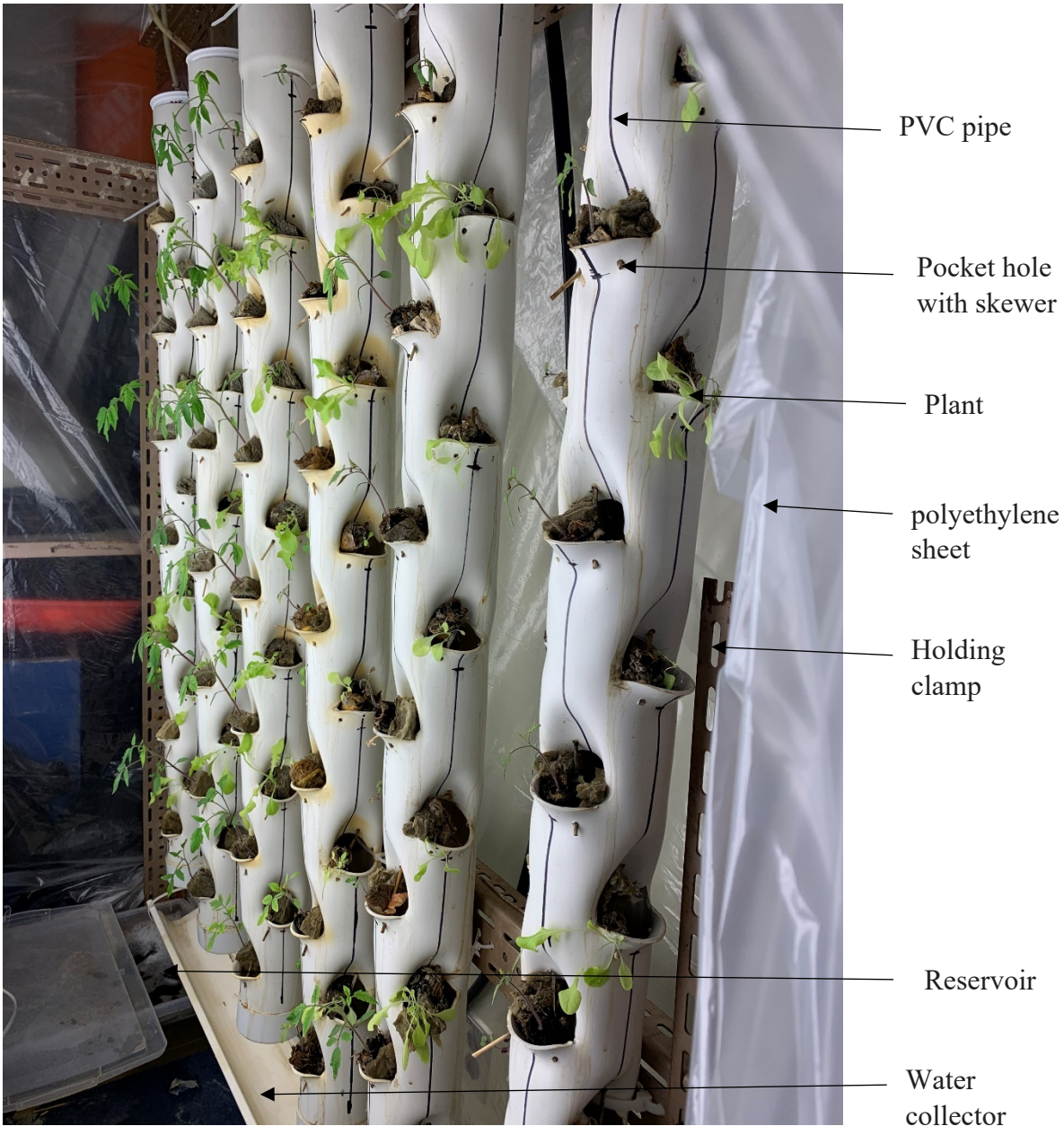

Figure 3.1: Aeroponic system with plants

The growing columns received water-nutrient solution through a shower-like reservoir at the top. Six flexible rubber tubes (length 0.76 m and diameter of 4 mm) were connected to emitters to supply water to the reservoir at the top. The water solution raining down each column was

collected in a channel at the bottom of the structure and returned to the water supply reservoir at the bottom. The water circulation was controlled by a short-period repeat cycle timer (BND-60/U97A, BN-Link Timer Intertek, US) to turn the pump on and off for predetermined periods (three minutes off/ten seconds on and six minutes off/ten seconds on), and the cycle repeated. Ríos Salazar et al. (2020) completed their experiment for arugula (*E. vesicaria* L.) plants with a frequency of 20 irrigations in one hour.

Each growing column had a vertical light stand directly opposite which was on for sixteen hours a day and off for the remaining eight hours. Each light stand had two fluorescent bulbs 1.2 m long (T-12-40W, 1800 lumens) connected via a 120V/60Hz ballast (0.43 meters from the front of the growing column). A heavy-duty timer (Intermatic, USA) was used to cycle the lighting. The experimental site temperature was 23.21˚C ±0.34˚C (controlled by central building heating system), and relative humidity was 63.15% ±2.08%. Water-solution pH was 7.75 ±0.02, and electrical conductivity (EC) was 0.56 ± 0.01 dS/m.

Nutrient supplement: Water with nutrients (Schultz, Premier Tech Home & Garden Inc, United Industries Crop.) was circulated through the aeroponic system. The nutrient supplements contained total nitrogen (N) 10.0%, available phosphate (P_2O_5) 15.0%, soluble potash (K_2O) 10.0%, iron (Fe) 0.10%, manganese (Mn) 0.05%, zinc (Zn) 0.05%, EDTA (Ethylene-di-amine-tetra-acetic acid) 1.01% (labelled on the package). The nutrient supplements were mixed with tap water in a ratio of seven drops of solution with one litre of water in a 25-litre water reservoir. The water-nutrient solution was supplied after the germination stage and was maintained in the aeroponic system throughout the entire duration of the experiment. Every 15 days, the water reservoir was cleaned, and the water-nutrient solution was refilled manually.

3.3 Measuring the physical and chemical properties of cattail blocks

Bulk density: Bulk density was measured by determining the specific volume of the substrate material used in the germination stage and measuring the oven-dry weight (dried at 105˚C for 24 hours) of the substrate material. The unit used to express bulk density is g cm^{-3}. Bulk density was measured by weighing a container (W1) then determine the volume (V) of that container by pouring water and measuring the volume of the water. After that, growing media was filled into the container. Oven dry weight (W2) of the container with growing media was measured. Bulk density was measured by following equation (Mudge 2023).

$$\text{Bulk density} = (W1-W2)/V \quad (3.1)$$

Total porosity, air-filled porosity and water holding capacity: The first step was to measure the volume of the experimental container: the container was cleaned and filled with water; the volume of water in the experimental container was recorded as the 'container volume'; the container was drained and dried then filled with the germination substrate by hand pressing. Using a measuring cup, the substrate material was carefully saturated until a thin film of free water appeared at the top of the substrate material line. The total volume of water added in this process was recorded as 'total pore volume' (British Columbia 2015). Once thoroughly saturated, the substrate media was lifted and hung above the experimental container with the help of a skewer until no more water drained into the container. The measured amount of this drainage water was recorded as 'aeration pore volume' (British Columbia 2015). The following equations were used to compute the total porosity, air-filled porosity and water-holding porosity (British Columbia 2015):

$$\text{Total porosity (\%)} = \frac{\text{Total pore volume x 100\%}}{\text{Container volume}} \quad (3.2)$$

$$\text{Air-filled porosity (\%)} = \frac{\text{Aeration pore volume x 100\%}}{\text{Container volume}} \quad (3.3)$$

Water-holding capacity (%) = Total porosity - Air filled porosity (3.4)

The pH and electrical conductivity: The pH and electrical conductivity (dS/m) of the substrate were measured by a laboratory pH meter and an Electrical Conductivity (EC) meter (Lumo-X multifunctional portable EC meter). The pH and electrical conductivity was measured on wet substrate material.

Assessment of Cattail Fibre Blocks as Growing Media Compared with Rock Wool

Three different plants, Astro arugula (*Eruca vesicaria sativa*), leaf lettuce (*Lactuca sativa*) and Roma tomato (*Solanum lycopersicum*) were used for assessing the development and growth rate during the germination stage and after transplanting into the aeroponic system.

Germination stage: Seeds were set for germination in rock wool and cattail fibre blocks on a heating pad to maintain a temperature of 22˚C - 24˚C. For each substrate, 18 Astro arugula, 18 leaf lettuce, and 21 Roma tomato seeds were set for germination. Each seed was set in a single substrate for rock wool and cattail block. Germination for rock wool and cattail fibre block was recorded daily for sprouted plants.

Transplant plant: All the successful plants were transplanted into the pockets of the aeroponic system 14 days after germination of the seeds. At this time, for both, rock wool and cattail block, 18 arugula, 18 lettuce and 21 tomato plants were transplanted into the aeroponic system. Two different irrigation schedules were used with motor off/on system as 3 minutes off/10 seconds on and 6 minutes off/10 seconds on.

At 35-day after transplanting all the plants were collected by cutting at the bottom of the plant and left for one hour to dry off any water droplets. The plants were weighed (fresh weight) at the Soil and Water Laboratory (University of Manitoba).

Statistical analysis

The data was analyzed to test for a significant difference ($p \leq 0.05$) in growth rate for different growing media and different irrigation schedules with ANOVA single factor analysis using Excel version – 16; t-statistics were used to test the significance of the slopes.

RESULTS AND DISCUSSION

3.4 Comparative analysis of essential properties of cattail block and rock wool

To check the suitability of cattail fibre for aeroponic application, selected properties were measured based on the work of Bilderback et al. (2005), Blok and Wever (2008) and Wallach (2008). Table 3.1 shows the properties of cattail and rock wool alongside the literature value for soilless growth media. The p-values in the table indicate the statistical significance for each property between cattail block and rock wool. (The detailed statistical analysis and procedure are given in Appendix – A, Tables 1 - 6).

Table 3.1: Comparison of essential properties of cattail block and rock wool (N=15)

Properties	Cattail block	Rock wool	P-value
Bulk density (g/cc)	0.09 ±0.002	0.1 ±0.004	0.00
Total porosity (%)	70.1 ±0.69	73.1 ±1.56	0.09
Air-filled porosity (%)	22.9 ±0.7	9.71 ±0.2	0.00
Water holding capacity (%)	47.3 ±0.9	63.4 ±1.4	0.00
Electrical conductivity (dS/m)	0.34 ±0.01	0.47 ±0.02	0.00
pH	6.34 ±0.08	7.7 ±0.08	0.00

Mean ±standard error

The properties show that cattail block was lighter than rock wool (bulk density: cattail 0.09, rock wool 0.1 g/cc), and the difference is statistically significant (p=0.00) (Appendix A, Table 1). The bulk density of rock wool found in the current study is within the range 0.032 to 1.52 g/cc

(Lublóy et al. 2022) found by Block et al. (2008) and Lublóy et al. (2022), while no such data is reported in the literature for cattail. The range of bulk density for soilless media has been found to be 0.19 – 0.70 (Bilderback et al. 2005).

The total porosity (%) of cattail fibre block was 70.13%; whereas, for rock wool the total porosity (%) was 73.13% and the difference is not statistically significant with p-value= 0.09 (Appendix A, Table 2). The range of total porosity (%) for soilless media is between 50 - 85% (Bilderback et al. 2005), air-filled porosity (%) is 10 – 30% (Wallach 2008), and water holding capacity (%) is 50 – 65% (Evans 2022). The air-filled porosity (%) and water holding capacity (%) remain within the literature value for both cattail and rock wool. Air-filled porosity (%) was higher for cattail block (22.9%) compared to rock wool (9.71%) and the difference is statistically significant (p=0.00) (Appendix A, Table 3). Water holding capacity (%) for cattail block was 47.26%, and rock wool had a value of 63.41% and the difference is statistically significant (p=0.00) (Appendix A, Table 4). For rock wool, Blok et al. (2008) found water holding capacity of 60%.

The electrical conductivity of cattail 0.34 dS/m as found less than the rock wool (0.47 dS/m) which is statistically significant (p=0.00) (Appendix A, Table 5). The pH of the cattail fibre substrate (6.34) was closer to the literature value than the rock wool (7.7) and the difference is statistically significant with p-value= 0.00 (Appendix A, Table 6).

Generally, most greenhouse plants prefer an acidic pH, in the range of 5.4 and 6.0 (Iersel 2020) and a growing media electrical conductivity (EC) between 1- 2.6 dS/m (Iersel 2020). A value of 0.5 dS/m and 7.6 for electrical conductivity and pH, respectively was reported by Tapia and Caro (2009).

Since the growing media remains very wet, algae growth is normal (Nemati et al. 2021). When the green algae become black and slimy, it can attract fungi and hinder water penetration

from drip emitters (Nemati et al. 2021). Therefore, porosity% is a very important property of the growing media. A higher air-filled porosity increases aeration, which helps to increase the oxygen supply and minimize an over-wet growing media. Whereas low air porosity leads to shortage of oxygen in the root zone which is a strong contributing factor to the spread of root pathogens (Nemati et al. 2021). Rock wool with low air-filled porosity (9.71%) shows the development of mould. The low air-filled porosity increases the growth of algae and mould by reducing the oxygen level in root areas. Moulds are known to produce poisonous substances—mycotoxins-that are a health hazard (USDA 2013). Mould growth was observed on rock wool during experiment.

3.5 Comparison of germination performance in cattail block and rock wool

Germination performance was assessed for cattail blocks and rock wool. Eighteen blocks of cattail and rock wool were used for Astro arugula and Leaf lettuce germination, while 21 blocks were prepared for Roma tomato seeds. This was repeated six times; therefore, 108 Astro arugula and Leaf lettuce seeds and 126 Roma tomato seeds were placed for germination in each cattail and the rock wool blocks.

Tapia and Caro (2009) found 87.60% lettuce seeds germinated in 7 days in rock wool. While no data is available for germination in cattail block, the difference found between the germination (%) in current study with that of the Tapia and Caro (2009) may be due to the growing conditions. The authors used greenhouse covered with black mesh (65% light), capillary irrigation system, and maintained 40°C (Tapia and Caro 2009), while the current study used ambient temperature, manual irrigation system (7 to 10 drops of water daily) with about 5 to 6 hours daily lighting conditions.

3.5.1 Comparison of germination for arugula plants in cattail block and rock wool:

Arugula seeds in cattail blocks showed more speedy germination than rock wool. After sprouting within three days, an average of 12.2 (67.8%) seeds in cattail block had germinated, whereas, in rock wool, only an average of 5.0 (27.8%) seeds had germinated. Further, after five days, 16.2 (89.8%) of plants sprouted in cattail blocks, but in rock wool, the rate was 12.7 (70.4%). During 3-day germination performance of cattail block and rock wool for arugula seed was statistically significant with p-value= 0.00 (Appendix A, Table 7) and during 5-day germination performance was statistically significant with p-value= 0.02 (Appendix A, Table 8) (Figure 3.2). All arugula seeds (N= 18) germinated in 7-day for both growing media cattail block and rock wool.

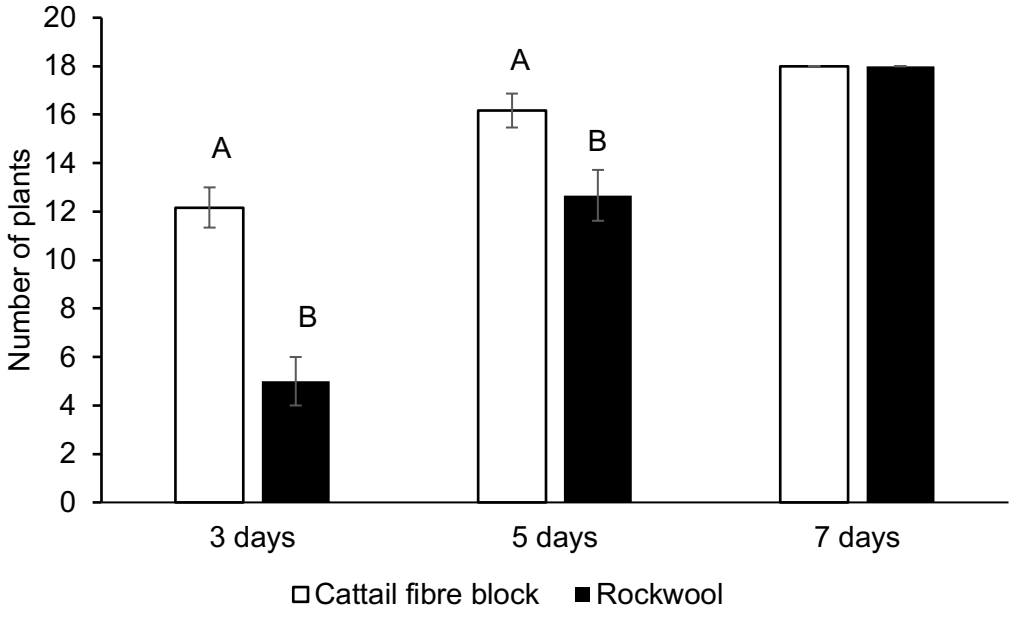

Figure 3.2: Comparison of germination performance for arugula seeds (N=6). Levels represent by different letters within a group are significantly different.

3.5.2 Comparison of germination for lettuce seeds in cattail block and rock wool:

Lettuce seeds in cattail blocks had speedier germination than in rock wool. Within five days, an

average of 12.0 (66.7%) lettuce seeds in the cattail block had germinated, while in rock wool, an average of only 5.0 (33.3%) lettuce seeds had germinated. After seven days, 15.8 (87.9%) of the sources had germinated in cattail blocks, but only 9.7 (53.7%) for rock wool. Germination performance of cattail block and rock wool for lettuce seed was statistically significant during 5-day and 7 -day with p-value= 0.00 (Appendix A, Table 9) and p-value= 0.00 ((Appendix A, Table 10), respectively. Germination performance was not statistically significant during 10-day with p-value= 0.34 (Figure 3.3). For both growing media, all the lettuce seeds (N=18) were germinated within 14-day.

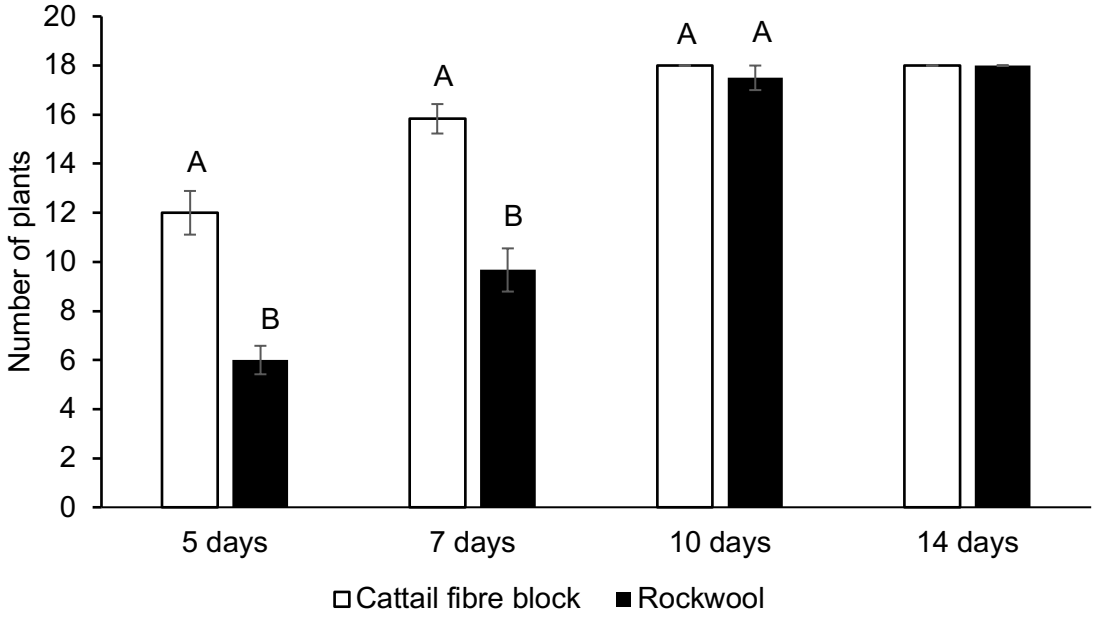

Figure 3.3: Comparison of germination performance for lettuce seeds (N=6). Levels represent by different letters within a group are significantly different.

3.5.3 Comparison of germination for tomato seeds in cattail block and rock wool:

The germination performance of tomato seeds in cattail blocks was better than in rock wool. The average of tomato plants seven days after seeding in cattail block was 8.2 (38.9%); however, rock wool had only 4.5 (21.4%). Further, after ten days, an average of 13.5 (64.3%) tomato seeds

germinated in cattail blocks, but only 10.0 (47.6%) for rock wool. Tomato seeds started germination after seven days in both growing media. Germination performance of cattail block and rock wool for tomato seed was statistically significant during 7-day with p-value= 0.00 (Appendix A, Table 11). For tomato seeds germination performance was not statistically significant for cattail block and rock wool during 10-day with p-value= 0.11 (Appendix A, Table 12) (Figure 3.4). All tomato seeds (N=21) were germinated in 14-day for both growing media.

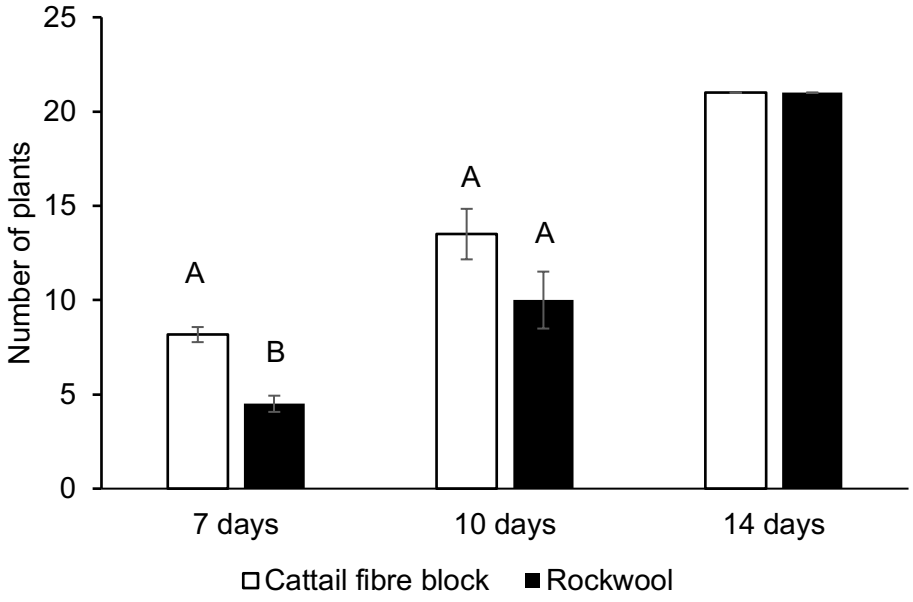

Figure 3.4: Graphical representation of germination time for tomato seeds (N=6). Levels represent by different letters within a group are significantly different.

3.6 Comparison of the growing media performance in aeroponics

The growth rate of arugula, lettuce and tomato plants was measured by the survivability (%) and average marketable weight of the transplanted plants in the aeroponic system during the post-transplant 35-day growing period (only plant shoot). Two different irrigation schedules (3 minutes off/10 seconds on; 6 minutes off/10 seconds on) were applied on the same aeroponic system to compare the growth rates in the different growing media (cattail block and rock wool).

Tapia and Caro (2009) found the average fresh weight of a lettuce plant (*L. sativa* var. *capitata*) at 1.67 g after 31 days during their experiment. Lei and Engeseth (2021) got an average weight of 45.21 ±5.85 g of lettuce after 55 days. Brockhagen et al. (2021) found the average fresh weight of spinach at 0.30 g and thyme at 0.019 g after 47 days of cultivation using hydroponics.

3.7 Comparison of the growth rate for 3 minutes off/10 seconds on the irrigation schedule

Plants survivability (%) in cattail block and rock wool

Arugula plants showed an average survivability of 94.4% in cattail block and 70.4% in rock wool which was statistically significant with p-value=0.00 (Figure 3.5). Cattail block performs better, probably for the mould growth on rock wool hinders the plants survivability.

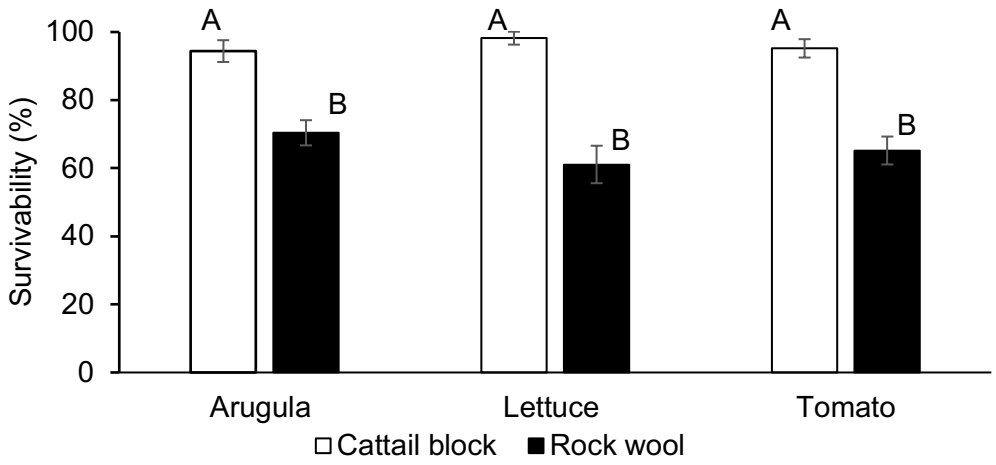

Figure 3.5: Comparison of plants survivability (%) in cattail block and rock wool. Levels represented by different letter within a group (similar plant) are significantly different.

In the three trial periods for cattail block, arugula plants showed 94.44, 88.89 and 100% survival rates, while in rock wool, the survival rate was 66.67, 66.67 and 77.78%.

Lettuce plants showed 98.2% and 61.1% survivability in cattail block and rock wool, respectively which was statistically significant with p-value=0.00 (Figure 3.5). In cattail block,

lettuce plants showed 94.44, 100 and 100% survival rates, while rock wool had only 55.56, 55.56 and 72.2%.

Tomato plants showed 95.2% and 65.2% survivability in cattail block and rock wool, respectively, statistically significant with p-value=0.00 (Figure 3.5). For the three-trial period (Figure 3.6) in cattail block, tomato plants showed 100, 95.24 and 90.48% survival rates, while rock wool showed 66.67, 71.43 and 57.43%.

Comparison of plants weight in cattail block and rock wool

Arugula plants have an average marketable weight of 0.25 ±0.02 g in cattail block and 0.27 ±0.02 g in rock wool with p-value =0.4, which was not statistically significant (Figure 3.6; Appendix A Table 13). Lettuce plants had an average marketable weight of 0.59 ±0.04 g in cattail block and 0.67 ± 0.06 g in rock wool with p-value =0.3, which was not statistically significant (Figure 3.6; Appendix A Table 14). In the cattail block, the tomato plant average weight was 0.72 ± 0.07 g, and in rock wool, the average weight was 1.27 ±0.16g with a p-value =0.03, which was statistically significant (Figure 3.6; Appendix A Table 15).

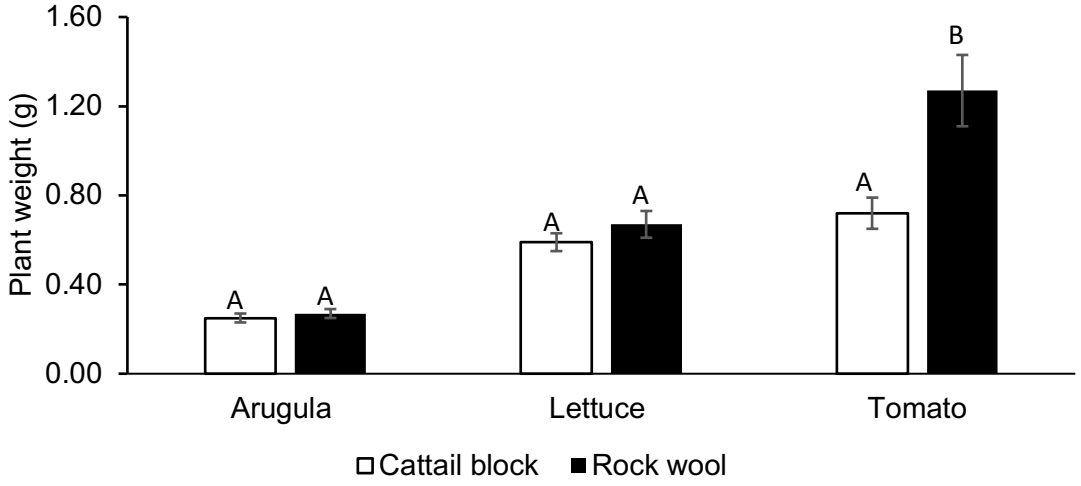

Figure 3.6: Comparison of plants weight in cattail block and rock wool. Levels represent by different letters within a group (similar plant) are significantly different.

3.8 Comparison of the growth rate for 6 minutes off/10 seconds on the irrigation schedule

Plants survivability (%) in cattail and rock wool

Arugula plants showed a survivability rate of 98.1% for cattail block and 62.9% for rock wool, which was statistically significant with p-value=0.00 (Figure 3.7). Arugula plants showed 100, 100 and 94.44% survival rates in cattail block for three trials, while in rock wool, the survival rate was 61.1, 66.67 and 61.1%.

Lettuce plants showed 94.4% and 66.7% survivability in cattail block and rock wool, respectively, which was statistically significant with p-value=0.00 (Figure 3.7). For the three trials in cattail block, lettuce plants showed 100, 88.9 and 94.44% survival rates, while rock wool had survival rates of 66.67, 72.2 and 61.1%.

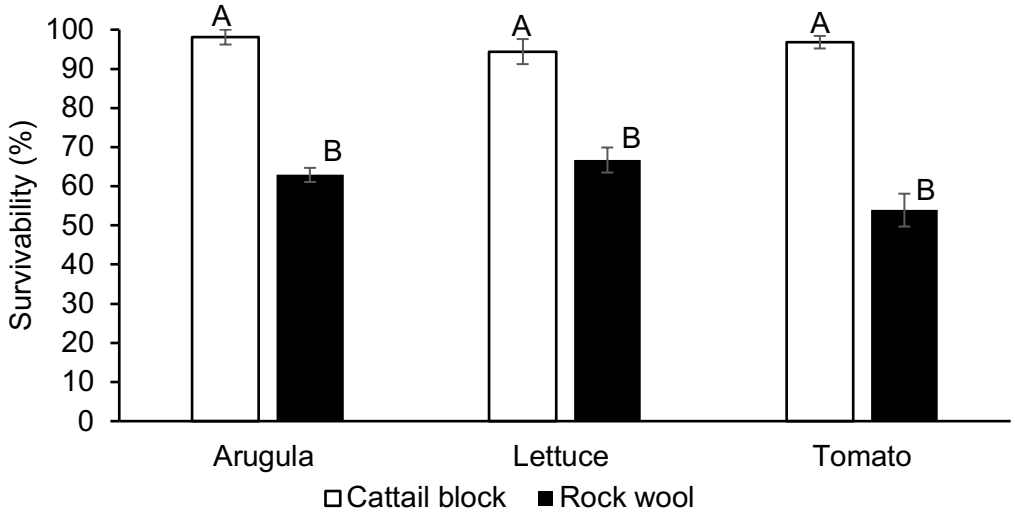

Figure 3.7: Comparison of plants survivability (%) in cattail block and rock wool. Levels represented by different letter within a group (similar plant) are significantly different.

Tomato plants showed 96.8% and 53.9% survivability in cattail block and rock wool, respectively, which was statistically significant with p-value=0.00 (Figure 3.7). During the three

trial periods in cattail block, tomato plants showed 95.2, 100 and 95.2% survival rates, while rock wool showed 61.9, 47.6 and 52.4%.

Comparison of plant weight in cattail block and rock wool

In cattail block, arugula plants had an average marketable weight of 0.22 ±0.04g, and in rock wool, the value was also 0.22 ±0.01 g with p-value =0.9, which means there was no statistical difference (Figure 3.8; Appendix A, Table 16). Lettuce plants had an average marketable weight of 0.28 ±0.02 g in cattail block and 0.45 ±0.03 g in rock wool with p-value =0.01, which was statistically significant (Figure 3.8; Appendix A, Table 17). The average tomato plant weight in the cattail block was 0.75 ±0.1 g; in rock wool, the value was 0.92 ±0.07 g with a p-value =0.2, which was not statistically significant (Figure 3.8; Appendix A, Table 18).

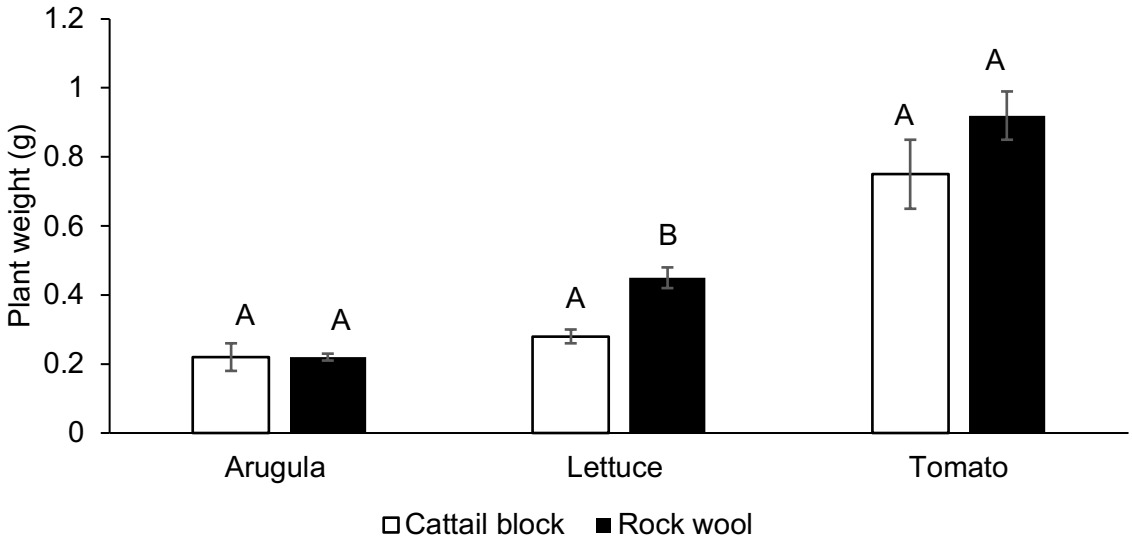

Figure 3.8: Comparison of plants weight in cattail block and rock wool. Levels represent by different letters within a group (similar plant) are significantly different.

3.9 Comparison of irrigation schedule on plant growth rate

Two different irrigation schedules (3 minutes off/10 seconds on; 6 minutes off/10 seconds on) were applied. The average fresh plant weight measured the growth rate of arugula, lettuce and tomato plants from the aeroponic system after a 35-day growing period.

The effect of the irrigation schedule was compared on the cattail block:

In the cattail block, the arugula plant had an average marketable weight of 0.25 ±0.02 g in the 3 minutes off/10 seconds on the irrigation schedule and 0.22 ±0.04 g in 6 minutes off/10 seconds on the irrigation schedule with a p-value =0.57, which was not statistically significant (Figure 3.9; Appendix A, Table 19). Lettuce plants had an average fresh weight of 0.59 ±0.04 g in 3 minutes off/10 seconds on irrigation scheduling and 0.28 ±0.02 g in 6 minutes off/10 seconds on with p-value =0.00, which was statistically significant (Figure 3.9; Appendix A, Table 20).

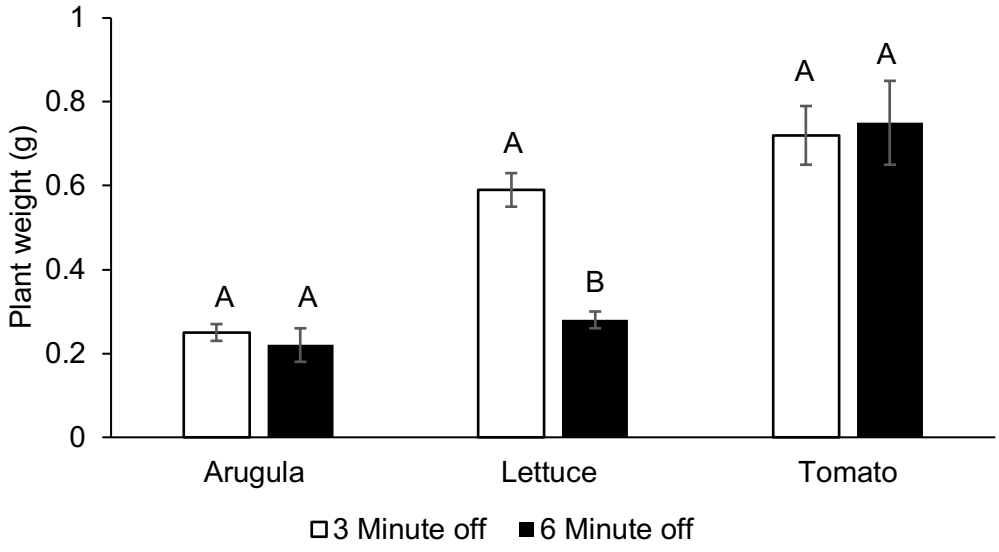

Figure 3.9: Effect of irrigation schedule on plant growth rate in cattail block. Levels represent by different letters within a group (similar plant) are significantly different.

In the cattail block, tomato plants had an average weight of 0.72 ±0.07 g in 3 minutes off/10 seconds on irrigation scheduling and 0.75 ±0.1 g in 6 minutes off/10 seconds on with p-value =0.84, which was not statistically significant (Figure 3.9; Appendix A, Table 21).

The effect of the irrigation schedule was compared on rock wool:

In rock wool, the arugula plant had an average weight of 0.27 ±0.02 g in 3 minutes off/10 seconds on the irrigation schedule and 0.22 ±0.01 g in 6 minutes off/10 seconds on with p-value =0.06, which was not statistically significant (Figure 3.10; Appendix A, Table 22).

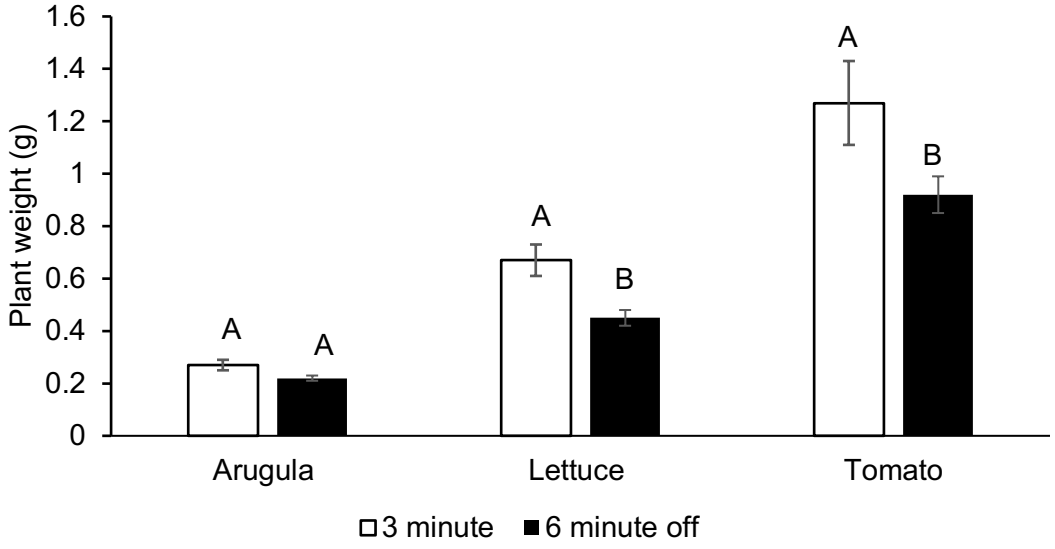

Figure 3.10: Effect of irrigation schedule on plant growth rate in rock wool. Levels represent by different letters within a group (similar plant) are significantly different.

Lettuce plants had an average weight of 0.67 ±0.06 g in 3 minutes off/10 seconds on the irrigation schedule and 0.45 ±0.03 g in 6 minutes off/ 10 seconds on with p-value =0.02, which was statistically significant (Figure 3.10; Appendix A, Table 22). In rock wool, tomato plants had an average weight of 1.27 ±0.16 g in 3 minutes off/10 seconds on the irrigation schedule and 0.92

±0.07 g in 6 minutes off/10 seconds on with p-value =0.11, which was statistically significant (Figure 3.10; Appendix A, Table 22).

CONCLUSIONS

The essential physical and chemical properties required for aeroponics, such as bulk density, total porosity (%), air-filled porosity (%), water-holding capacity (%), electrical conductivity, and pH of cattail fibres, are similar to that of rock wool. They are within the range of the suggested values.

For all three plants, growth in the cattail block was faster than in the rock wool. The germination of lettuce and tomato are statistically significantly earlier for cattail block compared to rock wool. During the growth stage, the plant survivability (%) was significantly greater in cattail for all three types of plants. The survivability (%) of all three plants was found to be above 90% for cattail block, whereas the survivability (%) was below 70% in rock wool. However, the plant weights were higher in rock wool than the cattail block, which was significant in the case of lettuce and tomato for both irrigation schedules.

It was found that the irrigation schedule significantly affects plant weight for lettuce in both cattail block and rock wool. However, for arugula and tomato, no significant effect was observed. Therefore, it is suggested that 6 minutes off/10 seconds on irrigation should be used for arugula and tomato rather than the 3 minutes off/10 seconds on schedule.

Cattail block has advantages as a soilless growth media over rock wool regarding germination rate and survivability. It was noticed that mould grew on the plants in the rock wool media; however, further research is required.

In conclusion, cattail blocks can be used as a substrate to replace rock wool to establish a sustainable aeroponic growing operation.

4. Preparation of cattail block and evaluation of selected properties of fibre

ABSTRACT

Growing media is an important element of soilless agriculture. The primary objective of this research is to replace the more common non-biodegradable synthetic substrate materials with natural cattail block. This research focused on the production of cattail block from cattail fibre. Cattail fibre was extracted from cattail plants (*Typha latifolia* L.) with alkali retting. The cattail blocks were prepared from the extracted dry fibre as growing media. Cattail block was used for 14-day seed germination followed by a 35-day growing cycle in an aeroponic system. The possibility of reusing the cattail fibre block was analyzed. Mechanical properties for raw and used cattail fibre were identical and the difference was not statistically significant with $p<0.05$. The moisture absorption (%) was similar for raw and used cattail fibre which was not statistically significant with $p<0.05$. Although, the difference for moisture desorption (%) was statistically significant with $p>0.05$. FTIR analysis showed similar peaks for raw and used cattail fibre. However, raw fibre showed some peaks for C=O and C=C stretching which was not seen for used cattail fibre. Overall, used cattail fibre can be reused as growing media.

Keywords: soilless vegetation, substrate, cattail fibre, mechanical properties, natural substrate.

INTRODUCTION

Soilless agriculture is becoming popular in both urban and rural areas. The systems are highly efficient in their use of water and nutrients (Barrett et al. 2016); are economical (Barrett et al. 2016; Grafiadellis et al. 2000); and give good plant yields (Barrett et al. 2016; Nejad and Ismaili 2014). A porous growing media, used instead of soil, supports the plants to grow and provide all the required nutrition and oxygen. To ensure proper growth of the plants, the growing media should retain air and water at appropriate ratios (Savvas and Gruda 2018).

An efficient substrate must possess specific physical, chemical and biological properties to support healthy root growth in a soilless system such as aeroponic system (Barrett et al. 2016). A suitable substrate should have an appropriate physical structure, size, and shape of the particles (Bilderback et al. 2005); bulk density (Blok and Wever 2008); particle size distribution and pore space (Blok and Wever 2008; Wallach 2008) to provide a good balance of air and water for the root growth, and for water retention capacity (Fonteno 1993). Therefore, the essential characteristics considered for selecting a substrate are absorption of water and nutrients, root growth, and root anchorage within the substrate (Blok and Wever 2008). Substrate size, height, and shape depend on the type of plant to be grown and the pot or container size in the system. Therefore, substrate size changes with the requirements of the aeroponic system.

Substrate performance is critically impacted by its biological properties. The effect of biological features of a substrate can be categorized into three main segments; pathogen development, biological stability and nutrient immobilization due to microbial growth (Barrett et al. 2016). Pathogens are harmful to human consumption as well as for plants. Therefore, the substrate material be resistant to pathogenic development that could cause harmful disease (Wever and Scholman 2011). The substrate material must be resistant to some degree of damage from microbial decomposition or chemical degradation, which may cause the physical instability of the

substrate (Jackson et al. 2009). Substrate material should be resistant to microbes which may consume nutrients supplied to the plants (Barrett et al. 2016).

Various types of growing media or substrates are used for soilless culture depending on the availability, cost, and plant growth performance. Currently, both synthetic and natural substrate materials are available for soilless culture. Rock wool is widely used as a soilless substrate in greenhouses. The production of rock wool is an environmental concern because of the high amount of chemicals and energy required.

Peat is prepared from different types of decomposed plant material. It has excellent physical, chemical and biological properties as a growing media; however, peat shows a wide variation in properties (Schmilewski 2008). Moreover, peat has a low re-wetting capacity which may hinder nutrient uptake and plant growth (Michel 2010). However, peat is used in horticulture industries for its flexible properties and lower cost (Barrett et al. 2016).

Coir fibre is a by-product of the coconut industry. Dust and short fibres derived from the fibrous husk of coconut are mixed. As a growing media, coir possesses good physical, chemical and biological properties, comparable to peat (Barrett et al. 2016; Nichols 2013; Schmilewski 2008). Coir fibre has an excellent re-wetting ability, which is advantageous over peat (Barrett et al. 2016; Blok and Wever 2008). However, since coir fibre is a by-product it is not processed specifically for substrate use (Barrett et al. 2016; Nichols 2013; Smith 1967). Because coconut trees are mainly found in (tropical) coastal areas, coir fibres may contain high phytotoxic levels of sodium and potassium (Nichols 2013; Schmilewski 2008).

The most popular natural fibres are cotton, wool, silk, flax, kenaf, and hemp. These fibres have been used in different applications for a long time. Ancient society used fibres obtained from nature to meet their basic clothing needs as well as for other essential items such as fishing nets

and ropes (Kozlowski et al. 2013). At present, waste biomass fibres, for example, cattail fibres are gaining popularity. The cattail plant grows abundantly, does not require maintenance, and the fibre extraction process is simple (Chakma 2018). Presently, *Typha* species has become a native plant in North American wetland regions. Primarily three species of cattail (*Typha)* are found in the North American regions: *Typha latifolia* L. (broad-leaf cattail) and *Typha angustifolia* L. (narrow-leaf cattail) (Smith 1967; Morton 1975). Studies found that harvesting of cattail in a wetland has commercial benefits due to the yield percentage of fibre (66%) (Chakma 2018). Cattail (*Typha Latifolia L.*) has been considered a potential crop (Anderson and Craig 1994) for its unique chemical composition, and usual extensive growth (Chakma et al. 2017). Also, cattail plants are beneficial for the environment in regard to their carbon sequestration, wetland restoration by wastewater management, and nutrient absorption that helps to avoid eutrophication in wetlands (Krus et al. 2014). Growing awareness of environmental issues has led to the increased demand for natural fibres. Researchers are working for continuous improvements of natural fibres to be applied in different types of engineered textile products other than the usual (more accepted) general textile uses.

This research introduces natural cattail fibre as an alternative to existing substrate (rock wool) material for aeroponic system. The replacement of the synthetic material (rock wool) with cattail fibre blocks made from naturally grown cattail plants (*Typha latifolia L.*) would be a unique approach toward sustainable development in soilless agriculture. Cattail fibres also demonstrate outstanding mechanical properties (diameter, tensile stress at break, tensile strain at break, and modulus) and chemical properties (moisture absorption (%) and desorption (%)) for substrate application. Since cattail plants are known as nutrient absorbers in aquatic locations (Grosshans et

al. 2011), a cattail fibre block could provide the necessary preliminary nutrients to plants in a soilless growing system.

Major mechanical properties of textile fibres are tensile strength, compressibility, extensibility (Adanur 1995). An essential property of substrate-making material is tensile strength, which is the resistance of fibre to break under tension. Durability, the ability of a fibre to retain its physical structure under conditions of mechanical pressure for a reasonable time (Hatch 1993), will determine whether the fibres are usable or non-usable for a substrate material. The physical properties of a fibre substrate are important to obtain the required substrate size and shape during preparation and to retain shape under stress. The substrate material must possess essential physical properties (fibre diameter, length, etc.) and mechanical properties (tensile stress at break, tensile strain at break, and modulus) for the preparation and formation of fibre block for successful use in the aeroponic system.

Moisture regain is the percentage of the mass of moisture to the oven dry state in a substance (Booth 1968). Moisture behavior is directly influenced by the sorption properties of cellulosic fibre (Hatch 1993). A number of water-attracting groups are hydroxyl group (-OH), amino group (-NH), amide group (-CONH) and some water reversing groups methyl *group* ($-CH_3$), carbonyl group (-COO) present in a cellulosic fibre structure (Hatch 1993). Moisture absorption has a considerable effect on fibre swelling, which is exhibited by cellulosic material where the water diffuses the material structure, block the areas of polymer chains and demonstrate a force outwards, initiating the material to swell (Booth 1968). The physical and structural changes of some material are caused by swelling (Booth 1968; Saville 1999) due to moisture absorption, which leads the substrate or fibre block to change structure dimensionally. FTIR (Fourier transform infrared) analysis helps to identify the chemical compounds present in the cattail fibre.

The essential mechanical and chemical properties of cattail fibre, as well as the environmentally friendly substrate preparation process, shows that cattail fibre (*Typha latifolia)* would be a good substrate material as an alternative to the present materials used. Therefore, this research investigated the suitable production process of cattail fibre extraction and preparation of fibre block as a growing media. The research analyzed the fibre yield (%) from young and mature cattail plants. Fibre yield (%) analysis is used to plan economical fibre production and forecast the amount of cattail plant required for the bulk production. The mechanical and chemical properties of both used and raw cattail fibre were assessed and compared.

The mechanical and chemical properties of cattail fibre make it suitable for automobile and packaging applications (Hasan 2019), and the hollow spaces in its structure make it appropriate for insulating materials (Liu et al. 2013). The objective now is to use the cattail block as a raw material in a completely different industry.

MATERIALS AND METHODS

4.1 Cattail block production process

Cattail plant collection: Cattail plants (*Typha latifolia* L.) were collected from the roadside canals and fields in different areas of Winnipeg, Manitoba (Canada). Young plants were collected during the month of April, and mature plants during the month of November. The plants were collected by cutting the stem at the bottom using scissors. There were approximately 5-6 leaves per plant, each about 1.5-2 m long for both mature and young plants.

Chemicals required for fibre production: Cattail fibre extraction was carried out for young and mature cattail plants in the same machine and with same chemical treatment. Cattail fibre extraction involves alkali retting with potassium hydroxide (KOH), neutralized with acetic acid (CH_3COOH). These chemicals were sourced from Fisher Scientific, ON, Canada.

Machine used for fibre production: An oscillating water bath (Advantec, Japan) located in the Textile Laboratory (W260, Duff Roblin, University of Manitoba, Winnipeg, MB, Canada) was used for the fibre extraction. Apart from this, equipment used included scissors, glass beakers, rods, sieves (1mm), measuring devices or balances, and flat drying tables. Fibres were individualized using a small carding machine located in the Textile Laboratory (W260, Duff Roblin, University of Manitoba, Winnipeg, MB, Canada).

Method of fibre production: The leaves were first separated from the plant stems. Then the leaves were cut into suitable pieces (0.10-0.12 m long). The cut pieces of leaves were weighed and stored for the following process.

Fibre production process: Retting is the popular method of bast fibre extraction. The essential fibre properties depend on the type of retting (Lee et al. 2020) and the time used for the retting. Fibre individualization would be difficult if under-retted; fibres would develop numerous weak zones on the surface if over-retted (Lee et al. 2020). The fibre extraction process involves multiple steps. The most effective fibre production method for cattail is alkali retting. Various alkaline solutions (such as NaOH, KOH, and LiOH) of different levels of concentration were observed for cattail fibre production. The NaOH retting was the most efficient with the most negligible impacts (Chakma 2018; Sana et al. 2014). Shadhin (2021) and Hasan (2019) efficiently extracted fibres from cattail plants by using KOH.

This research also used potassium hydroxide (KOH) with concentration level of 5% to extract fibres from cattail leaves. The chemical treatment time was four hours, and the temperature was 90°C. After completing the chemical treatment, fibres were collected in a strainer and washed in a cycle of 5 minutes of cold water followed by 5 minutes of hot water over a period of 30 minutes. The washed fibres were neutralized using 2% acetic acid solution for 30 minutes, then

washed again for 30 minutes in hot and cold water (as described above) and set in open air for drying.

4.2 Chemical treatment parameters in a closed water bath for fibre extraction

Potassium hydroxide (KOH): 5%

Material to Liquor: 1: 20

Temperature: 90˚C

Time: 4 hours

4.3 Fibre yield%

Cattail fibre yield (%) was calculated from the ratio of the mass of extracted cattail fiber to the mass of the cattail plants used for fibre extraction. Fibre yield (%) was measured for determine the quantity of fibre required to make specific amount of substrate.

4.4 Individualization of fibre for fibre block preparation

The web formation process and fibre individualization: Using a carding machine, the dried fibres were opened, cleaned, and arranged in a parallel direction to prepare them for fibre block production. The fibres were individualized from an entangled mass, opened, dirt particles and short fibres eliminated, finally making a uniform, non-woven web (Figure 4.1). This process aligns the fibres, which is important for root development in the aeroponic system. Since dirt and short fibres could block the water holes in the system it was necessary to eliminate these.

Figure 4.1: The carding machine used for non-woven web preparation.

4.5 Fibre block preparation

The dried fibres were softened by spraying a small amount of water to avoid breakage, and the non-woven web was prepared with the help of the carding machine (as described above) located in the Textile Laboratory (W260, Duff Roblin, University of Manitoba, Winnipeg, MB, Canada). The fibre blocks were prepared by rolling the non-woven web and tying with a cotton fabric string (Figure 4.2). These blocks were made in accordance with desired size and shape required for the aeroponic system and the plants to be grown. In this research, blocks were prepared in a cylindrical shape of one-inch diameter and one-inch in length.

Figure 4.2: Transformation of the non-woven web into cattail fibre block

4.6 Method of measuring mechanical properties of cattail fibre

Sample preparation: Two types of samples were prepared for the mechanical property investigation, raw sample and used sample. The raw cattail fibre was collected from the same source as was used for cattail fibre block preparation. The used fibre sample was collected from cattail blocks that had been used for single time for 14-day seed germination, followed by a 35-day growing cycle in the aeroponic system.

4.7 Determining fibre diameter

Single fibres were prepared for fibre diameter measurement. A single fibre was cut into a 30 mm length and attached to a square paper frame (1″ x 1″) using adhesives. All the single frames of fibre were kept in a desiccator for 48 hours to condition at 74% relative humidity. A Bioquant Analyzer and a microscope, located in the Mechanical Laboratory (Human Ecology building, University of Manitoba, Winnipeg, MB, Canada) were used for determining cattail fibre diameter. The square paper frame with cattail fibre was put on a glass plate and the fibre diameter was examined through the microscope applying a 10x magnification in Bioquant Analyzer (China) (Hasan 2019). A dedicated computer determined and recorded the fibre diameter. Due to the

variations in diameter through the length, diameters were measured at ten different places of the same sample, and the average diameter was calculated.

4.8 Determining fibre mechanical properties with Instron Tensile Tester

An Instron Tensile Tester located on the 5th floor of Duff Roblin building (University of Manitoba, Winnipeg, MB, Canada) was used to the measure mechanical properties of the fibres, according to the ASTM D 3822 standard test method. All the fibre samples were attached to a frame and conditioned in a desiccator for 48 hours at 74% relative humidity (as described above). The frame holding the single fibre was placed between the gripping jaws of the Instron Tensile Tester (Model: 5965, USA). The length of the fibre attached in the frame was considered as the gauge length of the fibre (25 mm). Then the vertical strands of the frame were cut with sharp scissors. For this research, the head with moving jaw pulled at a rate of 20 mm/min, using a 1 kN load cell. 'Instron Bluehill 3' software with a dedicated computer was used to conduct the tests (Hasan 2019).

4.9 Cattail fibre substrate chemical properties

Fourier transform infrared (FTIR) analytical technique was used for the chemical analysis of cattail fibre in FTIR (NICOLET 6700 Spectrometer, Thermo Fisher Scientific, USA) located at the Manitoba Institute for Materials building (University of Manitoba, Winnipeg, MB, Canada). Peaks from 4000 – 600 cm^{-1} were considered for analysis. Following the absorption peaks in the infrared spectroscopy, the chemical compounds and bonds of the fibre were categorized.

4.10 Moisture behaviour of cattail block

Moisture behaviour of cattail fibre was measured by determining the moisture absorption (%) and desorption (%). Samples were conditioned in a desiccator at 74% relative humidity for 48

hours using sodium chloride (NaCl) as desiccant. Then the samples were oven dried at a temperature controlled at 105 ±3°C for 48 hours. The weight of the samples was taken: a) before oven drying (W_r) weight of raw sample, room temperature 23°C, relative humidity 63%; b) after oven drying (W_o); and c) after conditioning in desiccator (W_d) (Montalvo and Von Hoven 2008). The moisture absorption and desorption of cattail fibre block were calculated from the following equations (4.1) and (4.2).

$$\text{Moisture absorption (\%)} = \frac{Wd - Wr}{Wr} \times 100\% \quad (4.1)$$

$$\text{Moisture desorption (\%)} = \frac{Wr - Wo}{Wr} \times 100\% \quad (4.2)$$

where, W_r = Weight of sample at raw stage,

W_d = Weight of sample after conditioning in desiccators,

W_o = Weight of sample after oven drying.

4.11 Statistical analysis

Collected data were analyzed to test for a significant difference ($p \leq 0.05$) with ANOVA single factor analysis using Excel version 16 for the mechanical and chemical properties of raw and used cattail fibre from cattail block.

RESULTS AND DISCUSSION

4.12 Fibre yield (%)

Fibre yield (%) was higher for mature cattail plants than young cattail plants, and the difference was statistically significant with p-value =0.00 (Appendix B, Table 1). Since the fibre yield (%) from young plants is much lower than from the mature plant, no further investigation was carried out using fibres from young plants. The input of chemicals, time and labour was identical for both plants. However, the output from young cattail plants was only

19.2%, and for mature cattail plants yield was 37.1%. Both fibres were mixed to make cattail blocks for the aeroponic system. The analysis indicates that fibre extraction from young cattail plants needs to adjust water content.

4.13 Comparison of raw and used cattail fibre

Fibre mechanical properties (diameter, tensile stress at break, tensile strain at break, and automatic young's modulus were analyzed. The chemical properties were compared for the raw and used cattail fibre by moisture absorption (%) and desorption (%). Chemical compounds were compared from FTIR analysis.

Mechanical property comparison (N =50): Comparison of mechanical properties for raw and used cattail fibres were shown (in Figure 4.3 – 4.7).

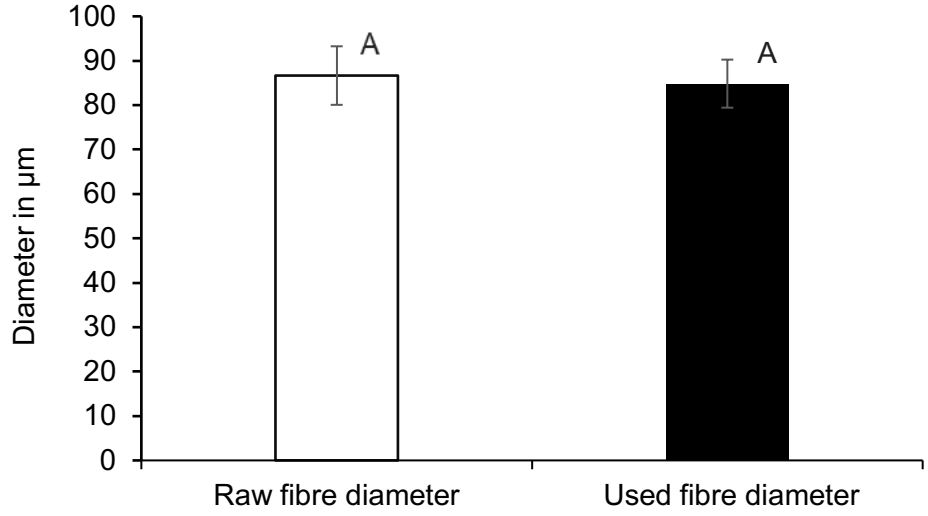

Figure 4.3: Comparison of fibre diameter for raw and used cattail fibre (N= 50). Levels represent by same letter within a group are not significantly different.

Cattail fibre diameter showed an average of 86.66 ±6.59 µm and 84.84 ±5.41µm for raw and used fibres, respectively (Figure 4.3); the difference was not statistically significant with p-value =0.83 (Appendix B, Table 2). Tensile stress was less for used cattail fibre at 163.20 ±18.84

MPa; whereas, raw fibre had around 227.09 ±30.26 MPa (Figure 4.4) and the difference was not statistically significant with p-value =0.07 (Appendix B, Table 3).

Figure 4.4: Comparison of tensile stress at the break for raw and used cattail fibre (N=50); Levels represent by same letter within a group are not significantly different.

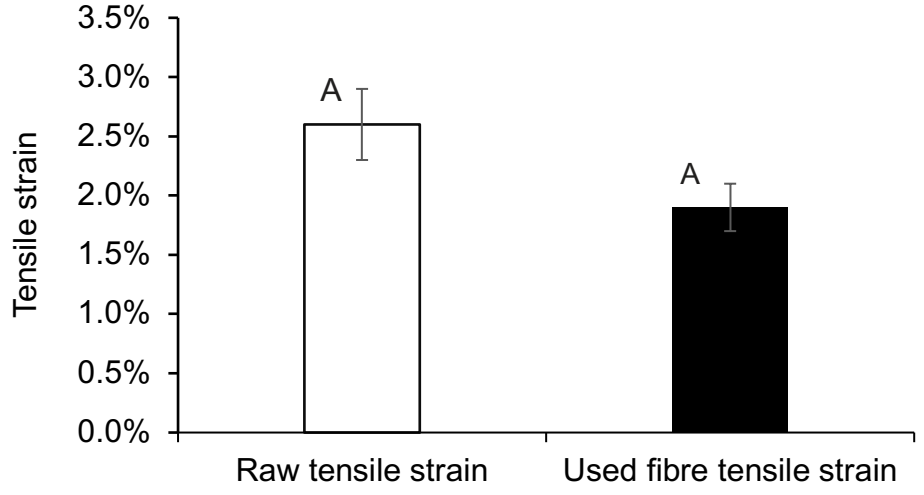

Figure 4.5: Comparison of tensile strain at the break for raw and used cattail fibre (N=50). Levels represent by same letter within a group are not significantly different.

Tensile strain (%) at break was also lower for used fibre at 1.9 ±0.2%; whereas, raw fibre performed at 2.6 ±0.3% (Figure 4.5). The difference was not statistically significant with p-value =0.06 (Appendix B, Table 4). Stress vs strain curve for raw has been shown in Figure 4.6 and for used cattail fibre in Figure 4.7.

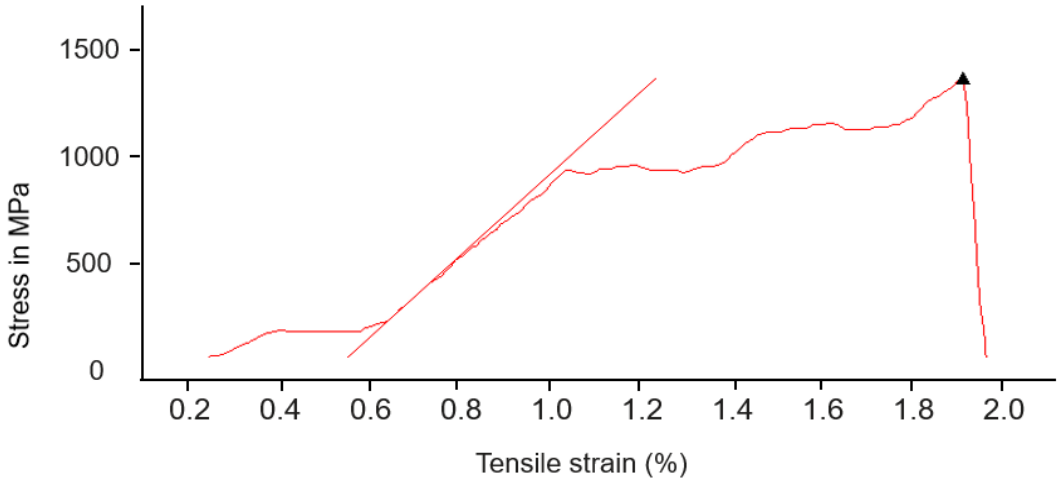

Figure 4.6: Stress vs strain curve for raw cattail fibre

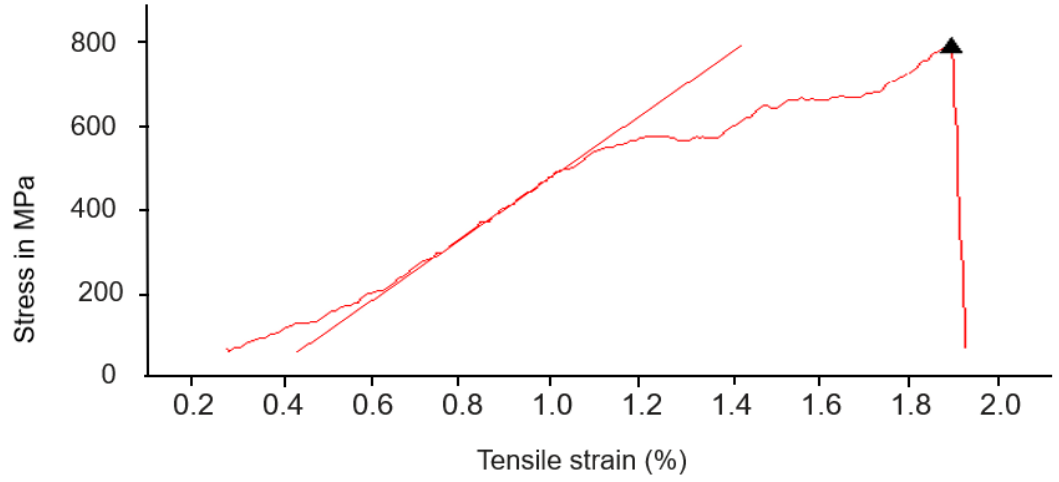

Figure 4.7: Stress vs strain curve for used cattail fibre

Raw and used fibre modulus (Automatic Young's) showed similar performance at 13.97 ±1.46 GPa and 14.08 ±2.11 GPa (Figure 4.6), and the difference was not significant with p-value =0.97 (Appendix B, Table 5).

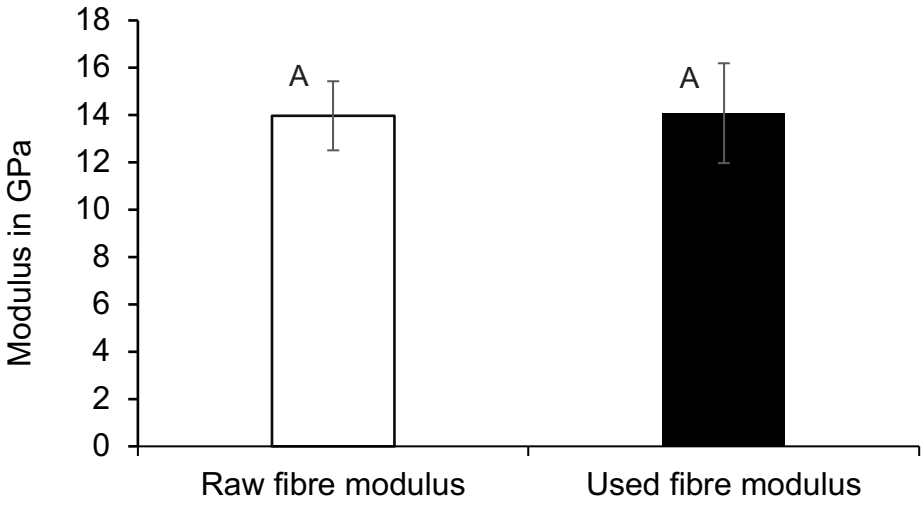

Figure 4.8: Comparison of modulus (Automatic Young's) raw and used cattail fibre (N=50). Levels represent by same letter within a group are not significantly different.

4.14 Moisture behaviour of cattail fibre (N =15)

Moisture absorption (%) of the raw cattail block was higher (2.23% ±0.1%) than the used cattail block (2% ±0.1%) (Figure 4.7) and the difference was not statistically significant with p-value =0.17 (Appendix B, Table 6). The moisture desorption (%) of the used cattail block was higher (6.44% ±0.65%) than the raw cattail block (4.94% ± 0.49%) (Figure 4.7) and the difference was statistically significant with p-value =0.00 (Appendix B, Table 7).

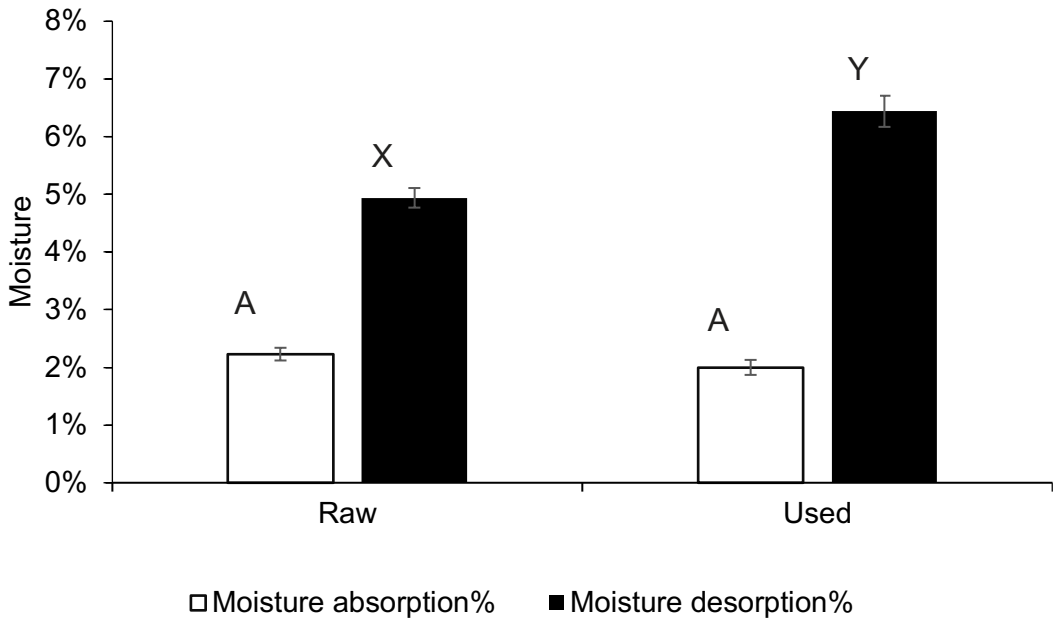

Figure 4.9: Moisture behaviour of raw and used cattail fibre (N=15). Levels represent by different letters within a group are significantly different.

The moisture absorption (%) for raw cattail blocks had a lower (2.23% ±0.43%) value considering the higher (4.94% ± 0.49%) moisture desorption (%). Similar performance was represented by the used cattail fibre block where the moisture desorption (%) (6.44% ±0.65%) was much higher than the moisture absorption (%) (2% ±0.13%).

4.15 FTIR analysis for raw and used cattail fibre

In Fourier transform infrared (FTIR) analysis (Table 4.1), the broad peak, ranging 3550 - 3100 cm^{-1}, could be linked to the stretching vibration of hydrogen and hydroxyl bond stretch with cellulose and hemi-cellulose. Both raw and used cattail fibre exhibited the peak within the range of 3550 - 3100 cm^{-1}. The peaks ranging at 2880 – 2980 cm^{-1} corresponded to the stretching of CH_2 and CH_3 and were related to the existence of vegetable wax in cattail fibre (Abdullah et al. 2010). Both raw and used cattail fibre had peaks at this range.

Table 4.1: Fourier transform infrared (FTIR) analysis for the raw and used cattail fibre

Peak (cm^{-1})	Raw fibre	Used fibre	Peak (cm^{-1}) Literature value	Chemical group
3331	Yes	Yes	3100 - 3550	hydrogen and hydroxyl bond in cellulose and hemi-cellulose (Sana et al. 2014)
2921	Yes	Yes	2880 - 2980	Methylene stretching in cellulose (Cesar et al. 2015)
2360	Yes	No	2400-2000	carbonyl group stretching (Sigmaaldrich.com 2022).
1597	Yes	No	1600 - 1650	alkyne stretching (Sigmaaldrich.com 2022)
1315	Yes	Yes	1310 - 1390	phenol bond (Sigmaaldrich.com 2022)
1030	Yes	Yes	1030 - 1085	primary alcohol (Cesar et al. 2015; Dave et al. 2013)

In addition, both raw and used cattail fibre had peak value ranging at 1085 - 1030 cm^{-1} of the strongest band. These peaks exhibit the C-O in cellulose, hemicelluloses, and lignose, all indicating cattail fibre is a cellulose fibre (Likon et al. 2013). Raw cattail fibre showed peaks in the range of 1600 – 1650 cm^{-1} and 2400-2000 cm^{-1} for C=C stretching, alkene and O=C=O stretching, respectively. However, used cattail fibre did not show peaks in those ranges indicating the lack of carbo=carbon and carbon=oxygen in the used cattail fibre.

CONCLUSIONS

The data analysis indicated that the fibre yield from young and mature cattail plants was not the same. Extracted cattail fibre yield was higher for mature plants compared to young plants. Therefore, manufacturers could easily forecast the amount of plant that should be collected for the required amount of fibre to produce the quantity of substrate block. The use of green cattail plant for fibre extraction needs to consider and adjust the water content. Therefore, the yield (%) was lower for green cattail plants.

Fibre mechanical properties do not vary for used and raw cattail fibre. Neither did mechanical properties show any significant change for raw and used cattail fibre. Shadhin (2021) and Liu et al. (2013) found that cattail fibre was a suitable raw material for composite industries. Hasan (2019) found the optimum values of fibre properties to be used in automobile application: diameter 79.83 µm, tensile strength 165.6 MPa, modulus of elasticity 14.01 GPa, elongation at break 1.53%, and moisture regain 8.9%. For packaging industries application: diameter 87.76 µm, tensile strength 145.2 MPa, modulus of elasticity 13.2 GPa, elongation at break 1.44%, and moisture regain 9.1%. However, the values of mechanical properties of used cattail fibre block were near the range of optimum values for automobile and packaging applications provided by Hasan (2019). Therefore, the cattail fibre obtained from used cattail substrate has the possibility to be utilized in the automobile and packaging industries.

The moisture absorption rate of cattail fibre was identical for raw and used cattail fibre. However, the moisture desorption rate was different. The FTIR analysis illustrates that the major chemical compounds appear in both raw and used cattail fibre. Raw cattail fibre had C=C stretching and O=C=O stretching, while the used cattail fibre did not have these carbo=carbon and carbon=oxygen bonds. The probability of these missing double bonds could be due to the cattail use in the aeroponic system; in water, the double bond (covalent bond with carbon) in carbon

breaks and makes a H-bond with water. For this reason, the moisture desorption (%) was higher for used cattail fibre. The lower numerical value for mechanical properties of used fibre could have been due to the breakage of these covalent bonds and a weak H-bond. Further investigation is required for detailed evaluation and verification.

In conclusion, cattail blocks used in the aeroponic system for one growing cycle have the possibility of being used in automobile, packaging, insulating or composite industries.

5. CONCLUSION

Aeroponic systems provide a sustainable food production system that could be accessible even in locations in extreme environments. Therefore, the growing media used in aeroponics should be natural and sustainable. This research investigated the suitability of novel cattail fibre block as the growing media in aeroponic systems. The cattail block was compared with the currently used rock wool, which is a synthetic material. This research involves the preparation of cattail fibre block and then evaluating the cattail blocks in the aeroponic systems.

The essential properties for growing media were comparable for cattail block and rock wool. Therefore, cattail block has the suitability of using as growing media.

Germination performance was better for all three experimented plants (arugula, lettuce, and tomato) in cattail block than in the rock wool. Cattail block showing speeder germination after 3 days and 5 days than rock wool which was statistically significant. Germination performance of cattail block and rock wool for lettuce seed was statistically significant after 5 days and 7 days. Tomato seeds showed higher germination rate on cattail block after 7 day with statistically significant difference. Therefore, cattail performs better regarding germination for arugula, lettuce, and tomato seeds.

Plant growth was assessed by plant survivability (%) and plant fresh weight for two different irrigation schedules. Plant survivability (%) was statistically significant for all three plants and for both irrigation schedules in cattail block than rock wool. However, plant weight was higher for rock wool than cattail block. Plant weight was higher in rock wool for tomato plants for 3 minutes off irrigation schedule, which was statistically significant. For 6 minutes off irrigation schedule, plant weight was statistically significant in the case of lettuce. Considering the plant growth performance, cattail performs better based on the survivability (%).

The 3 minutes off irrigation schedule showed better performance which was statistically significant for lettuce in cattail block. In the case of rock wool, 3 minutes off performs better for lettuce and tomato which was statistically significant.

Mechanical and chemical properties of cattail fibre are suitable for industrial applications. Further, the comparison of raw and used cattail fibres indicates that cattail fibre is suitable for reuse following its use as a growth media. On the other hand, rock wool causes pollution problems in waste disposal. It was evident that the rock wool had developed mould; however, further research in this area is required to determine the causes.

In conclusion, cattail block can be used to replace rock wool as a substrate for sustainable soilless agriculture processes and reduce CO_2 emission. The organic classification of vegetables grown in the cattail fibre block needs to be investigated.

FURTHER RECOMMENDATIONS

The aeroponic system was enclosed with polyethylene sheets to avoid a drop in temperature and light. Pollinating bees and other insects are necessary for fruit production. Pollination of the tomato plants did not occur in the aeroponic system for this research. Therefore, the tomato plants had no fruit in any of the six trials. Further research could explore the production of fruits in the aeroponics system.

The mould in the growing medium was not investigated further. Therefore, further study on the type of mould growing in the rock wool could be carried out. Further research could investigate the resistance of mould and fungal growth in cattail fibre.

To transplant the germinated seeds in aeroponic systems this research used bamboo skewers to hold the plant with substrate placed in the pocket of column. The end point of this pocket needs to seal to avoid the water droplets splashing outside.

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Appendix A

Table 1: ANOVA single factor analysis for bulk density of cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.002	1	0.002	9.68	0.004	4.09
Within Groups	0.007	38	0.000			
Total	0.009	39				

Table 2: ANOVA single factor analysis for total porosity% of cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	90	1	90	3.09	0.09	4.09
Within Groups	1104.38	38	29.06			
Total	1194.38	39				

Table 3: ANOVA single factor analysis for air-filled porosity% of cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1729.23	1	1729.23	320.78	0.000	4.09
Within Groups	204.84	38	5.39			
Total	1934.07	39				

Table 4: ANOVA analysis for water holding capacity% of cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2608.23	1	2608.23	94.49	0.000	4.09
Within Groups	1048.84	38	27.60			
Total	3657.07	39				

Table 5: ANOVA analysis for electrical conductivity (EC) of cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	178756.9	1	178756.9	28.16	0.00	4.09
Within Groups	241194.7	38	6347.23			
Total	419951.6	39				

Table 6: ANOVA single factor analysis for p^H of cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18.62	1	18.62	155.27	0.00	4.09
Within Groups	4.56	38	0.12			
Total	23.18	39				

Table 7: ANOVA analysis for germination of arugula after 3 days in cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	154.08	1	154.08	30.31	0.00026	4.96
Within Groups	50.83	10	5.08			
Total	204.92	11				

Table 8: ANOVA analysis for germination of arugula after 5 days in cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	36.75	1	36.75	7.63	0.02	4.96
Within Groups	48.17	10	4.82			
Total	84.92	11				

Table 9: ANOVA analysis for germination of lettuce after 5 days in cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	62.5	1	62.5	27.17	0.00081	5.32
Within Groups	18.4	8	2.3			
Total	80.9	9				

Table 10: ANOVA for germination of lettuce seeds after 7 days in cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	114.08	1	114.08	33.39	0.00018	4.96
Within Groups	34.17	10	3.42			
Total	148.25	11				

Table 11: ANOVA for germination of tomato after 7 days in cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	40.33	1	40.33	39.03	0.000095	4.96
Within Groups	10.33	10	1.03			
Total	50.67	11				

Table 12: ANOVA for germination of tomato seeds after 10 days in cattail block and rock wool

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	36.75	1	36.75	3.02	0.11	4.96
Within Groups	121.5	10	12.15			
Total	158.25	11				

Table 13: ANOVA analysis for growing media performance in the case of the arugula plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00107	1	0.001067	0.8	0.4	7.708
Within Groups	0.00533	4	0.001333			
Total	0.0064	5				

Table 14: ANOVA analysis for growing media performance in the case of lettuce plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.010417	1	0.010417	1.39	0.30	7.708
Within Groups	0.029867	4	0.007467			
Total	0.040283	5				

Table 15: ANOVA analysis for growing media performance in case of tomato plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.448267	1	0.448267	10.49	0.03	7.708
Within Groups	0.170867	4	0.042717			
Total	0.619133	5				

Table 16: ANOVA analysis for growing media performance in the case of arugula plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.67	1	1.67	0.0073	0.9	7.708
Within Groups	0.009067	4	0.002267			
Total	0.009083	5				

Table 17: ANOVA analysis for growing media performance in case of lettuce plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.040017	1	0.040017	19.68033	0.01	7.708
Within Groups	0.008133	4	0.002033			
Total	0.04815	5				

Table 18: ANOVA analysis for growing media performance in case of tomato plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.046817	1	0.046817	1.931912	0.2	7.708
Within Groups	0.096933	4	0.024233			
Total	0.14375	5				

Table 19: ANOVA for effect of irrigation schedule on cattail block in case of arugula plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001067	1	0.001067	0.372093	0.57	7.708
Within Groups	0.011467	4	0.002867			
Total	0.012533	5				

Table 20: ANOVA for effect of irrigation schedule on cattail block in case of lettuce plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.138017	1	0.138017	35.08898	0.00	7.708
Within Groups	0.015733	4	0.003933			
Total	0.15375	5				

Table 21: ANOVA for effect of irrigation schedule on cattail block in case of tomato plant

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001067	1	0.001067	0.046852	0.84	7.708
Within Groups	0.091067	4	0.022767			
Total	0.092133	5				

Appendix B

Table 1: ANOVA analysis for fibre yield (%) of mature and young cattail plants

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	570.55	1	570.55	20.83	0.000035	4.04
Within Groups	1314.97	48	27.39			
Total	1885.52	49				

Table 2: ANOVA analysis for fibre diameter

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	82.81	1	82.81	0.05	0.83	3.94
Within Groups	178019.9	98	1816.53			
Total	178102.8	99				

Table 3: ANOVA analysis for fibre tensile stress at break

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	102043.8	1	102043.8	3.21	0.076	3.94
Within Groups	3113261	98	31767.97			
Total	3215305	99				

Table 4: ANOVA analysis for fibre tensile strain at break

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001	1	0.001	3.73	0.06	3.94
Within Groups	0.027	98	0.000			
Total	0.028	99				

Table 5: ANOVA analysis for fibre modulus (automatic young's)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.31	1	0.31	0.002	0.97	3.94
Within Groups	16081.57	98	164.09			
Total	16081.88	99				

Table 6: ANOVA analysis for raw and used cattail fibre moisture absorbency%

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00004	1	0.00004	1.99	0.17	4.19
Within Groups	0.00059	28	0.00002			
Total	0.00064	29				

Table 7: ANOVA analysis for raw and used cattail fibre moisture desorption%

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.0017	1	0.0017	22.94	0.00005	4.19
Within Groups	0.0021	28	0.00007			
Total	0.0038	29				