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Using an Agricultural Supply Chain to Train the Next Generation of STEM Professionals

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At the University of South Florida (USF) she leads the project coordination for the National Science Foundation Florida Alliance for Graduate Education and the Professoriate (FL-AGEP), a $2.4M award to Florida A&M University (with a subaward to USF and Virginia Tech), Bethune-Cookman University, Florida International, and Florida Memorial University. Also, Dr. Johnson Austin is the project coordinator and Co-Principal Investigator for the USF Project Racism In School Exclusionary Suspensions (RISES), a $30k grant awarded to explore the suspensions of African American middle and high school students in Hillsborough and Pinellas County Florida.

Dr. Johnson Austin held positions as: math faculty at Academy Prep Center of Tampa; executive director of Curated PathwaysTM to Innovation; senior vice president for operations at the National Action Council for Minorities in Engineering, Inc.; president and CEO of St. Michael's High School; executive vice president of the Community Partnership for Lifelong Learning; executive director of the National Consortium for Graduate Degrees for Minorities in Engineering and Science; and Minority Engineering Program director at The Pennsylvania State University. She began her career as a cost engineering at Bechtel Power Corporation. In 2007 she founded Charis Consulting Group, LLC.

Dr. Johnson Austin was recognized by numerous organizations for her work in promoting equity and access to STEM education. Her most notable award is the 2015 Outstanding Engineering Alumnus in Civil and Environmental Engineering from The Pennsylvania State University. In addition, she was awarded the 2004-2005 Selected Professions Fellowship by the American Association of University Women (AAUW). Dr. Johnson Austin was awarded in 2007 the Strengthening Our Communities Inaugural Community Educational Leadership Award at the 2nd Annual Celebrate Literacy Conference. In 1998, she was recognized with the National Society of Black Engineers' (NSBE) Inaugural Golden Torch Award for Minority Engineering Program Director of the Year and the Outstanding Contribution by a Minority Engineering Program Administrator Award by the National Association of Multicultural Engineering Program Advocates (NAMEPA).

She is a member of various STEM organizations including the United States White House endorsed initiative under the Obama Administration, Algebra by 7th Grade, and advisory committee member for the Smithsonian Science Education Center's 'Zero Barriers in STEM Education.' Dr. Johnson Austin is currently the President of the American Association of University Women Tampa, Inc., consultant to the board for the Caribbean Community Association of Tampa, and Treasurer for the Northeast STEM Starter Academy of Mount Vernon, NY.

Dr. Johnson Austin is a member of the editorial review board for the Caribbean Educational Research Journal (CERJ). She also served as a reviewer for the National Science Foundation's CS for All Pathways, HBCU-Up, INCLUDES Conference and INCLUDES Launch Pilot.

She enjoys doing yoga, spending time on the beach, and mentoring young girls and women in STEM studies and careers.

Jiangnan Peng

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Abstract

The market for microgreens as a specialty crop is gaining increased attention as concerns about global warming, food insecurity, food supply chain and food safety have become salient issues among consumers, food cultivators, and food regulators. The farm-to-table concept continues to trend and attract followers and adoptees, and many stakeholders (including consumers, local growers, restaurateurs, and grocery stores owners) are eager to learn more about the economic prospect of the microgreen movement. In a science, technology, engineering, mathematics (STEM) academic setting, microgreens, which are harvested 7 to 14 days after germination, are ideal for teaching underrepresented students about food and nutrition. We are interested in conducting research that investigates how to grow, harvest, and transport microgreens using quantitative analytic and systems engineering tools. Specifically, we will highlight our undergraduate and graduate student researchers and their progress in learning how various STEM disciplines can be applied to address agricultural problems.

1.0 Introduction

1.1 About our Research Team

Morgan State University, Prairie View Agricultural and Mechanical University, and Tennessee State University are collaborating on a National Science Foundation (NSF) Historically Black College and University Undergraduate Program (HBCU-UP) Award #2000244. Our research team was formed at the NSF sponsored HBCU Engineering Faculty workshop hosted by the Association of Public & Land-Grant Universities (APLU) at the Tennessee State University back in May 2018. The purpose of the three-day workshop was to assist HBCU Engineering faculty with: (1) Improving student learning in engineering; (2) Sharing innovative strategies to improve the retention and graduation of engineering students: and (3) Providing tools and strategies for developing grant proposals and effectively competing in national grant solicitations.

We were one of five teams managed by Charis Consulting Group, LLC, who collaborated, submitted, and were awarded an NSF HBCU-UP grant. Given that HBCU-UP is designed to strengthen STEM undergraduate education and research at HBCU, we leveraged our research efforts by targeting the Research Experiences for Undergraduates (REUs) to fund undergraduate students at our respective institutions. Each undergraduate student was mentored by a principal investigator (PI) at each institution. A webinar series was created for the REU students to learn first-hand how to conduct research related to the experimental, analytical, biological, and industrial components of our project. Outside of the REU experiences we also provide research experience through internal university programs and for graduate students throughout the year. This paper will highlight the various projects students worked on related to microgreens at each institution.

1.2 About Microgreens

Microgreens are plants that are edible but only grown to a juvenile stage. As a result, microgreens have short, repeatable cultivation cycles - around seven to fourteen days per harvest. However, within these short cycles, microgreens are capable of producing compounds (phytochemicals) that offer a plethora of health benefits, at significantly higher levels than their mature counterparts. Illustrative studies have shown that specific classes of microgreens can be enzymatically activated to form special phytochemical-derived compounds with antioxidant, antimicrobial, and anticancer properties. For this research we specifically focus on broccoli sprouts (Figure 1). Thus, the unique properties and characteristics of the microgreen life-cycle provide strong motivation for a microgreen-driven "medicine-to-table" movement.

Figure 1. Broccoli Microgreens

Microgreens can be grown in indoor or outdoor environments (i.e., greenhouses or growth chambers) using three different media which are soil or soilless [1]. The soilless methods include aquaponics or hydroponics. Most microgreens or plants can be grown in various soil combinations (i.e., peat or coconut coir) [2]. This is the standard method for growing. Aquaponic growing systems in Figure 2 utilize the feeding of fish to fertilize plants [2]. Hydroponic growing systems in Figure 3 utilize pads where the seedlings are put, and an irrigation system is used to water the plants. These methods have been shown to decrease contamination risk.

Figure 2. Aquaponics

Figure 3. Hydroponics

As the population becomes more health conscious many consumers are seeking fresh quality food items. It is important to develop and manage supply chain systems that allow for quality food to be distributed to the end consumer. Within perishable food supply chains there are four main areas that can affect microgreen production; these are shelf life or perishability, transportation, supply chain coordination, and cost. The first phases of the food supply chain are critical for perishable food products because they involve the growing and cultivation stages. Product freshness drives consumer demand and leads to an increase in purchases [3]. Many perishable foods have various nutrients that are needed for our bodies to function. It is important to transport them at their highest quality in a timely manner to consumers. According to [4] transportation contributes to food waste, as well as uses 10% of our total energy in the United States. This can especially impact food going to urban areas. Research on coordination within the agricultural supply chain is limited [5]. Coordination is important because it helps us to understand the interdependencies among the various actors and activities, which can assist with redesigning the supply chain at various nodes in order to increase profit margins. Lastly, from the cost perspective the time from the supplier to the end consumer is where most perishable food items go through degradation, which accounts for loss of sales and inventory to the retailer and consumer [3].

2.0 Project Goals and Objectives

Table 1. Collaborative Research Components and Projects

Collaborative Research Components	Student Projects
Experimental Component (Tennessee State University)	Project 1: Bringing Microgreens to the Social Scene Project 2: Disparity between Urban and Suburban Communities in the Availability of Broccoli Microgreens Project 3: The Marketability of Microgreen Kits and Increasing Microgreen Consumption
Analytical Component (Morgan State University)	Project 1: Synthesis of the Reference Standard 1,3-benzodithiole-2-thione Project 2: HPLC analysis of Total Isothiocyanates
Biological Component (Prairie View A&M University)	Project 1: The Impact of Variable Glucosinolate Degradation Rates on Microgreen Transportation Delivery Time Featuring Fixed-Target Sulforaphane Intake Concentration Level Project 2: A Preliminary Study on the Techno-economic Feasibility of Industrial-scale Microgreens Production
Industrial Component (Morgan State University)	Project 1: Broccoli Microgreen Supply Chain Analysis for the Pre-Harvest Stage Project 2: Discrete Event Simulation for a Broccoli Microgreen Supply Chain

The research plan consists of four main components: experimental, analytical, biological, and industrial (Table 1). The experimental component is led by Tennessee State University. For this phase of the project an emphasis is placed on the growing, cultivation, and harvesting of microgreens. Under this component two undergraduate and one graduate student participated in research projects related to understanding consumer perceptions, product availability, and marketability to underserved communities for microgreens. The analytical component, led by Morgan State University, focuses on validating the optimized life cycle of the microgreens and testing levels of the phytochemical sulforaphane in microgreens. Student projects for this component consists of developing a standard to testing and analyzing isothiocyanates. The biological component is led by Prairie View A&M University. This phase of the project highlights the optimization of the growth conditions by phytochemical production targeting, growth media and analyzing metabolic pathways. The student projects associated with this component study the degradation of glucosinolates and their impact on designing industrial-scale microgreen production. The industrial component is also led by Morgan State University. This phase of the project evaluates the complete supply chain network from production to the end consumer with a focus on preventing perishability and optimizing the distribution of broccoli microgreens. The student projects center around understanding the areas in pre- and post-harvest stages of a microgreen supply chain in order to identify bottlenecks in order to optimize the total system. Sections three through six highlight each student project related to each component (Table 1).

3.0 Experimental Component Projects

3.1 Research Overview

One of the aspects that was attractive to the researchers and students in the Foods and Nutritional Sciences, Human Sciences Department at the Tennessee State University, was that Calabrese microgreens are high in isothiocyanate sulforaphane and are known to prevent certain cancers [6]. Therefore, they conducted laboratory experiments to analyze the growth cycle and nutrient content of the Calabrese microgreens. The human sciences ecological framework was used to study how the Calabrese microgreens could improve the lives of students, researchers, and stakeholders at the individual, family, community, and environmental level. Students also collected qualitative data from local farmers, and consumers on their perceptions, awareness, and acceptability of Calabrese microgreens. Their projects spanned social applications, disparities between urban communities, and increasing consumption and marketability of microgreen kits.

3.2 Project 1: Bringing Microgreens to the Social Scene

"Bringing Microgreens to the Social Scene" proposed developing a mobile application that informs users about microgreens, growing tips, and nutrient information. The application would allow users to watch videos, chat with others, "ask the expert", and share personal experiences.

The application could connect and share on social media apps such as Tik Tok, Snapchat, Facebook, and Twitter. The student wanted to examine how promoting microgreens through an interactive mobile phone application increases consumer popularity, knowledge, and consumption. Three main questions: 1) How does a mobile phone application for microgreen promotion affect consumer popularity? 2) How does a mobile phone application for microgreen promotion affect consumer knowledge? and 3) How does a mobile phone application for microgreen promotion affect consumer consumption? The student developed a proposal mapping the development of a phone application in four segments.

The first step would be to use the latest IOS mobile application software and obtain an Apple Developer license to obtain, own and run a mobile application. Specific coding is necessary and requires someone with coding skills. The student proposed using Adobe Photoshop Design and Corel Drawing to design the appearance and layout of the application. For this project, the student only wanted a mock application to show a mock-up of the mobile application. The next step was to survey potential consumers' opinions regarding an application's proposed features and technological capabilities dedicated to growing microgreens. Additional questions around accessibility preferences. The third step in the proposal involved testing the application using focus groups to test the applications and provide feedback to direct changes to the application. The last step would be to determine whether or not using a microgreen mobile phone application increased consumption and knowledge of microgreens.

In addition to conceptualizing the steps of developing a mobile phone application, the students had to include a timeline and budget in their proposals and then present the proposal to the project team for feedback. The student would use that feedback to polish their final written proposals. The process of researching and writing a proposal was beneficial for the students to help them think about how to solve problems in their communities using science and technology. It also allowed them to discuss their ideas and answer questions designed to help their critical thinking skills. This student was very interested in food security and health disparities and interested in promoting microgreens among African Americans and had the idea that since most people use smartphones, a better way to increase consumption of microgreens and help with food insecurity would be to develop a phone application, "*Microgreen Scene"* that provides education and support around the benefits of growing microgreens.

3.3 Project 2: Disparity Between Urban and Suburban Communities in the Availability of Broccoli Microgreens

"Disparity Between Urban and Suburban Communities in the Availability of Broccoli Microgreens" proposed to examine the inventory of microgreens in local grocery stores in Nashville (Davidson County), Tennessee. The student proposed to evaluate the nutritional environment of the stores and consumers using two survey instruments to determine the disparity between urban and suburban communities in the availability of broccoli microgreens. Consumers will complete an anonymous five-question Qualtrics survey on their knowledge, consumption of microgreens, and zip code. A visual assessment of the grocery stores using the Nutrition Environment Measures Survey in Stores (NEMS-S) will rate the nutrition environments of the communities. Using Qualtrics, the student proposed to distribute a short survey with the following questions to the university campus: 1) What are broccoli microgreens? 2) How often do you consume them? 3) Are you aware of their health benefits? 4) Are they accessible at your local grocery store? and 5) What is your zip code? This student acknowledged the importance of obtaining institutional approval to conduct research before collecting human subject data.

3.4 Project 3: The Marketability of Microgreen Kits and Increasing Microgreen Consumption

The primary aim of this graduate student project was to increase the consumption of microgreens in the United States. As a candidate of the MBA program, this student's project aimed to answer the research question, "What is the best way to create and fill a niche for microgreens?" Her project included evaluating the types of microgreen kits sold on Amazon, test piloting a "home kit" targeting children in grade school to teach science concepts and introduce indoor gardening to families. As part of the preliminary work, the student proposed interviewing stakeholders at various levels. Teachers, school administrators, local and national microgreen growers, and families would be interviewed to determine the current knowledge and consumption of microgreens amongst the stakeholders.

Her preliminary research found that kits were available to grow plants of many varieties but that no farms within the State of Tennessee sold such kits that allow consumers to efficiently grow microgreens on their own and learn more about the benefits. This student's research sought to determine what consumers think about microgreen kits and how having a kit fit into their lifestyle. Overall, this project proposed to investigate the current market for microgreen kits, the best fit marketing plan, and gain insight from consumers, parents and educators.

The purpose is to discover reasons the average American family does not grow microgreens in their home, and what would influence them to start. This proposed study examines potential barriers of purchasing a microgreen kit by asking what are consumer's subscription habits, what are consumer's interest in growing microgreens, and what are consumers looking for when buying a kit? By interviewing persons from different industries and sectors, this research may determine the most profitable niche for microgreens and how to create affordable kits and curriculum. While this option may increase agricultural knowledge about microgreens and growing food in the home, this may not be the best way to increase microgreen consumption in the United States.

Potential benefits of conducting this project include helping us determine what consumers know and want and how we can meet their needs. I need funding to collect and analyze qualitative data from parents, educators, corporate and agriculture professionals. Information gathered may help innovate and stimulate the microgreen market. There is a large online market for kits to grow vegetables indoors. We found several varieties on Amazon, ranging from around $30 to more than $200, both with small and large business retailers. The proposed interviews with business owners selling microgreen kits can provide information about the industry, target market, competitors, pricing and forecast. In addition, the student proposed interviewing growers at their nurseries and education companies that sell science kits to school-age children to research their sales and distribution processes.

The research sought to answer the following questions: (1) If reducing the barriers to growing microgreens in the home or in any environment, will more people grow them? (2) What do consumers need to grow their food at home? (Such as materials, space, time, resources.) (3) What are the marketing and educational tools needed for retailers to be successful and sell microgreen kits? and (4) How do educational companies maintain consumers in specific markets?

Table 2. Breakdown of Target Audience

Target	Definition/What it includes	Purpose
Families	Newlyweds, families with kids, families without kids, families of all varieties	Researching this segment will tell more about what we need to encourage families to grow microgreens in the home.
Educators	All teachers K-12	Researching this segment will tell more about educators' need for a microgreens kit to succeed in a school and school systems.
Farms	Farms that grow microgreens	Researching this segment will tell more about the growing process and feasibility of growing microgreens in the home.
Educational Corporate	Educational companies that distribute agricultural kits	Researching this segment will tell more about the distribution and sales process

In this study, interviews are conducted with participants from all four categories about their consumption of microgreens, their usual vegetable consumption, gardening experience, and their thoughts on a microgreens kit. The market analysis includes growing, documenting, interviewing the business owners/operators and staff of the facilities to learn more about the market and the potential profitability of selling microgreen kits. In visiting the farms, after arranging the visit with each farm, this discovery grant will cover the cost of travel to each facility, tour the facility, and document their growth, sales, and distribution process. A market analysis will examine different products available on the market. The proposed market analysis included growing the microgreen kits purchased on Amazon, documenting their growth, rating the kits, and communicating with the business owners about business operations, marketing, and distribution challenges. The student's proposal included a budget and timeline for collecting data.

4.0 Analytical Projects

4.1 Research Overview

Broccoli microgreens contain a large number of glucosinolates, which give the isothiocyanates (ITCs) after enzymatic hydrolysis. ITCs are actually the active components to exert the chemopreventive activities, in addition to many other health beneficial effects, such as antioxidantal, anticancer, antibacterial, and prevention of cardiovascular diseases. For this reason, the total isothiocyanates will be analyzed for this project. The cyclocondensation method is perfect for the measuring of total isothiocyanates. The principle is that all isothiocyanates react with 1,2-benzenedithiole to form the same product, 1,3-benzodithiole-2-thione, which has a unique ultraviolet (UV) absorption at 365 nm [7]. The concentration of 1,3-benzodithiole-2-thione then can be easily measured by UV spectroscopy or HPLC [8; 9]. We adapted the HPLC analysis method in our laboratory because it is more sensitive and accurate.

4.2 Project 1: Synthesis of the Reference Standard 1,3-benzodithiole-2-thione

The reference standard, 1,3-benzodithiole-2-thione, for this analysis is not commercially available. The purpose of this project was to perform synthesis of this standard. In the literature current methods for the synthesis of this standard takes a long time (>5 hours) and requires multiple steps of purification, which includes partition, column chromatography, and crystallization. This project aims to develop an improved method to perform rapid synthesis of 1,3-benzodithiole-2-thione. A student researcher tested the yields and kinetics of the reaction in different solvents without the buffer. The results indicated that both methanol and methylene chloride give a similar yield of the reaction. However, the reaction rate in methanol is much faster than in methylene chloride. The reaction in methanol was completed in 20 minutes. Pure product can be obtained just by evaporation and crystallization as shown in Figure 4. Crystallization solvents were also tested. Although solubilities are different in chloroform, methylene chloride, and methanol, the yields are slightly different. The purity of this standard is checked by HPLC. This method is much faster and simpler than the current method.

Figure 4. Crystallization from methanol

4.3 Project 2: HPLC analysis of Total Isothiocyanates

The goal of this project was to establish an analytical method to quantify the total isothiocyanates in microgreens. To reach this goal, sample processing and HPLC methods were developed. Fresh microgreens are ground and incubated with a pH 8.5 buffer to produce isothiocyanates. The isothiocyanates react with 1,2-benzenedithiol to produce the 1,3-benzodithiole-2-thione. The concentration of 1,3-benzodithiole-2-thione was then determined by HPLC. HPLC was performed using a Shimadzu Hamp Analyzer system. A Shimadzu NexLeaf 150 × 4.6 mm, 2.7 □m C18 column was used for the HPLC analysis with a gradient elusion of 85% to 100% methanol. A linear curve was established with a R^2 of 0.9998 (Figures 5 and 6). The concentration of the sample was calculated based on the correlation equation.

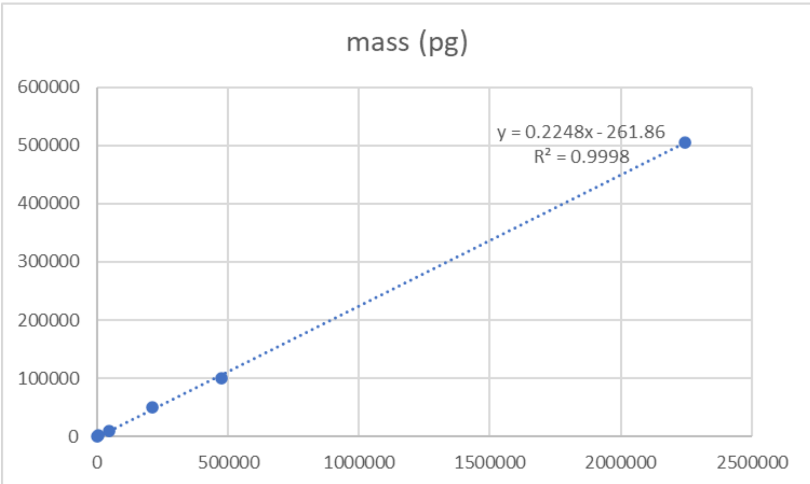


Figure 5. The calibration curve of 1,3-benzodithiole-2-thione.

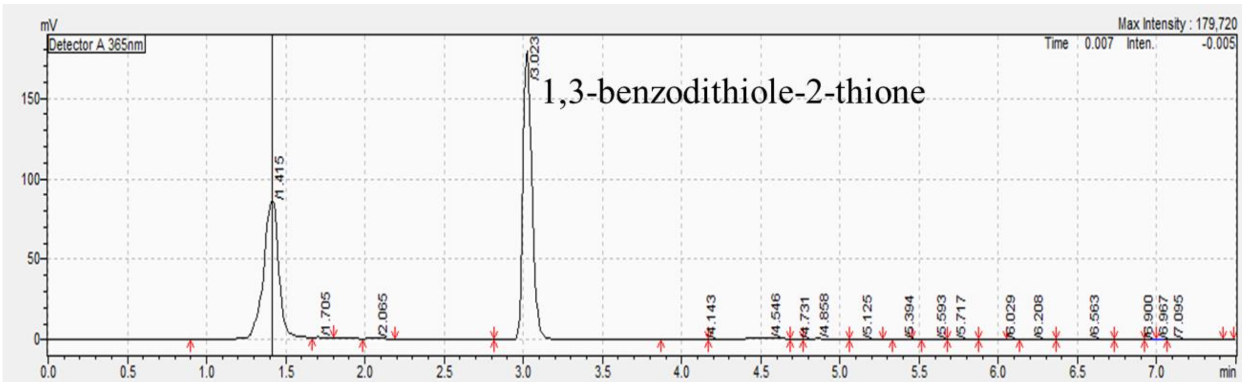


Figure 6. Chromatogram of microgreen sample

5.0 Biological Projects

5.1 Research Overview

In recent years alternative, non-chemo approaches to the treatment and prevention of cancer-related illnesses have received increased attention. One alternative involves consumption of microgreen products in dried or fresh produce form. Microgreens are edible plants that are grown to the juvenile or first true leaf stage. They comprise high concentrations of sulfur-rich phytonutrient compounds known as glucosinolates. Upon chewing, glucosinolates in microgreens are enzymatically converted into sulforaphane – a chemical disruptor of proliferation signaling pathways in cancer cells.

Key challenges limiting the use of microgreens as a viable preventative or therapeutic alternative for cancer treatment include (among many others): (i) increasing the concentration of glucosinolates in microgreens to levels that convert to an optimal sulforaphane intake and – because glucosinolate concentration levels in microgreens degrade upon harvest – (ii) identifying optimal transportation strategies to ensure delivery of microgreens with glucosinolate content sufficient to establish sulforaphane efficacy. In these studies, we will separately explore the effect of glucosinolate degradation on maximum recommended delivery times and their potential implications on the design of industrial-scale microgreens production.

5.2 Project 1: The Impact of Variable Glucosinolate Degradation Rates On Microgreen Transportation Delivery Time Featuring Fixed-Target Sulforaphane Intake Concentration Level"

The study focused on growing broccoli microgreens for these benefit an industrial ecosystem to see if it will be sustainable. Research has been done to determine the scale of one tray of broccoli microgreens and its yield. Two methods were used, manipulating variables yielding higher nutrients: soil-based and hydroponic systems. The results of this research prove that it was both sustainable and profitable to grow an indoor ecosystem of broccoli microgreens using both the soil method and the hydroponic system. The parameters, data, and models were then able to further our research to determine how to immediately harvest our broccoli microgreens and transfer them from the warehouse to Whole Foods. Then from Whole Foods directly to the consumer to maximize the amount of glucoraphanin in the broccoli microgreens and reach the consumer's table.

Glucoraphanin converts into sulforaphane on a one-to-one stoichiometric mole basis. We found that a glucoraphanin concentration range between 0.88-1.10 μmol/g is common in fresh-weight broccoli microgreens [10]. Based on literature values, we assumed an average microgreens sample comprises a 0.85 μmol/g glucoraphanin concentration [11]. This means that 0.85 μmol/g of glucoraphanin can yield up to 0.85 μmol/g of sulforaphane in the body. Students used this information for modeling to determine the minimum dosage per gram of glucoraphanin needed to be therapeutically efficacious. Students then developed analytical models to represent glucoraphanin degradation based on a rate constant for microgreens with a 13% water content. $k_{d,ref}$ represents the degradation rate constant in minutes at T_{ref}, a reference temperature chosen to be 100°C or 373 K. The reference data was used to identify a sample degradation rate constant at 25°C or 98 K for $k_{d,ref} = 2.07 \times 10^{-2}$ per minute using an Arrhenius-type model. The activation energy for glucoraphanin degradation, E_a, is 159 J/mol [10].

We formulated our model as a first order differential system in terms of glucoraphanin concentration in microgreens micromoles per gram. The model was used to determine glucoraphanin degradation from a Whole Foods location in Houston, TX to consumers in various surrounding areas. The study assumed an initial glucoraphanin concentration of 0.85 μmol/g, and a k_d equal to 0.027 per minute. To find the maximum allowable travel time between the Whole Foods and a consumer's home, t_{max}, we needed to identify the glucoraphanin concentration threshold that maps to a minimum sulforaphane concentration needed to constitute an efficacious dose.

G_{min} = Minimum glucoraphanin concentration needed for an efficacious dose

t_{max} = Maximum time before glucoraphanin concentration degrades past recommended dose

Since the average glucoraphanin concentration is 0.85 μmol/g, eating 1/2 cup of broccoli microgreens per day is recommended, equivalent to 43 g of broccoli microgreens per day. We then found that it would be 9.27 moles per gram of glucoraphanin within the 43 g of micro greens. This yields a glucoraphanin concentration minimum of 0.22 μmol/g.

The results of this study were based on an analysis of areas in Houston, Texas. Only one Whole Foods sold broccoli microgreens in the Houston area. The results for minimum glucoraphanin concentration recommended to treat cancer and maximum time before glucoraphanin concentration degrades passed the recommended dose.

$$G_{min} = 0.22\ \mu mol/g$$

$$t_{max} = 50\ minutes$$

The implications of these findings suggest that accessibility to microgreens with ideal phytonutrient characteristics is largely geography-dependent. For example, living in an affluent area (likely (near a Whole Foods) almost guarantees that a consumer can achieve a recommended diet of glucoraphanin-containing microgreens at efficacious levels (drive times < 15 minutes). Moreover, even consumers living in some socioeconomically depressed communities in the city can also acquire appropriate quality microgreens (Sunnyside drive time is 25 minutes or Frenchtown < 30 minutes drive time or Missouri City < 30 minutes drive time). However, consumers living in surrounding counties or in rural communities will not be as successful. Towns in Waller County (a neighboring county) have drive times of up to and over 60 minutes to the nearest Whole Foods with fresh microgreens. Consequently, consumers living in these areas would need to consume more than half a cup of broccoli microgreens to reach the recommended daily dose. Associated costs for fresh microgreens and transportation costs may prohibit these consumers from availing themselves of the natural benefits of microgreens.

5.3 Project 2: A Preliminary Study on the Techno-economic Feasibility of Industrial-scale Microgreens Production

The purpose of this REU project is to design an industrial-scale system to cultivate and harvest microgreens. Our analysis assumes the acquisition of a land-based greenhouse facility with dimensions: length = 125 feet; width = 125 feet; and height = 22 feet would be suitable to generate six (6) dry tons of microgreen harvests on an annual basis. We determined that the greenhouse structure with the dimensions identified can be acquired for approximately $500,000. Operating costs, which include administrative costs and utilities such as fuel and electricity, are $45.54 per dry ton of microgreens produced. Our studies of aquaponic production methods using the same greenhouse facility indicate that the costs associated with water-based microgreen production is comparable to terrestrial systems of cultivation. It is important to note that the analysis presented here focuses on microgreen cultivation and harvest. The complexities of post-harvest microgreen processing (aside from drying) and transport were not addressed in this study.

There are recent studies that provide rudimentary market analysis of microgreens in general without emphasis on the Brassicaceae family or broccoli microgreens. [12]. These studies underscore the emerging market for microgreen products, the environmental favorability of microgreens, and the positive societal impact of an increase in microgreen availability. Id. In particular, researchers perform analyses of the environments associated with a microgreens market using a PESTLE framework – which identifies the political (P), economic (E), sociocultural (S), technological (T), legal (L), and environmental (E) forces influencing a market. The political environment (P) is favorable towards increased microgreen production. For example, the Farm Bill of 2018 provided the USDA's National Institute of Food and Agriculture with up to $10 million of annual funding toward a competitive grant program supporting the development of urban, indoor, and emerging agriculture practices (USDA) [12]. The economic environment (E) is perceived to be favorable for a microgreens market. Microgreens trade at a premium when compared to other vegetables, with average prices ranging from $25-$45 per pound. [13]. The sociocultural environment (S) is favorable for microgreens production when considering those living with higher socioeconomic status. A 2016 Pew Research Center survey estimates that most adults purchase organic food because of perceived health benefits, while the second most common reason to purchase organic is for perceived benefits to the environment [14]. These studies also provide an assessment of the legal and environmental factors (L and E) that may lead to a robust microgreens market.

Surprisingly, this literature does not provide an in-depth technical analysis (T) or a detailed treatment of broccoli microgreen cultivation and harvest strategies that encompasses economic viability (T and E). Fortunately, there is guidance for how to conduct a rigorous albeit preliminary analysis of production methods for commodity crops like microgreens [15]. A baseline areal space floor plan for microgreen cultivation is shown in Figure 7. Included in this representation is shelving for growing microgreens in vertical space. Shelfing (region highlighted in gray) can be used for either soil-based or aquaponic growth strategies. Accommodations are made for spacing for aisles in between each row of shelves. Twenty-five percent of the total space budget is reserved for harvest storage, power generation, and product transport. Floor plans for land-based and hydroponic growing systems can be treated as similar. However, a hydroponic system will require a water filtration system as part of the storage and power generation space budget.

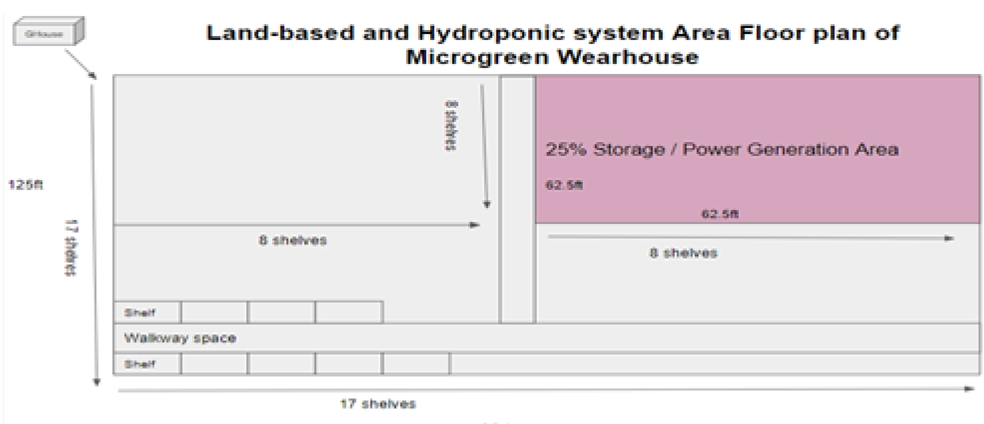


Figure 7. An areal floor plan for both land-based and hydroponic growing systems.

The daily harvest of microgreens, A_{DH}, can be found from the hourly harvest rate (A_H) and the total hours of harvesting per day (t_D):

$$A_{DH} = A_H t_D$$

From that calculation, we were able to find the mass of broccoli plants harvested daily, M_D, is found from the daily yield per harvester and the density of broccoli microgreens (ρ_B):

$$M_D = A_{DH} \rho_B$$

Finally, daily yield is used to determine the electricity costs shown in Table 1 below. Electricity needs are directly related to the amount of energy required for pressing or drying, P_P, for the drying process is modeled as a function of time-power per ton, the mass of microgreens produced per hour (M_p), and the rate of microgreen drying ($R_{M,press}$) (hourly):

$$P_p = \left(18 \frac{hp - hr}{ton}\right) * \left(\frac{M_p(hr)}{907}\right) * (1 - R_{M,press})$$

To find the total energy used for the press, we accounted for the total power required for pressing and the total number of presses on-site:

$$P_{PT} = N_p P_p$$

After calculating the key operating parameters in our broccoli microgreen land-based and hydroponic systems in the computations above, it was determined that the resulting operating cost will be $45.54 per dry ton biomass.

In summary, our analysis suggests that a greenhouse facility sized to produce 6 tons of broccoli microgreens will incur operating expenses of only $45.54 per dry ton with a potential sale value of $25-$45 per pound, according to literature estimates. Although a more rigorous economic evaluation is needed, these preliminary results suggest that an economically viable transition from small-scale to large-scale microgreen production appears promising. The bright-side implication is that, from a production perspective, broccoli microgreens can be scaled to address food insecurity and nutritional deficiency concerns facing underserved communities. In future work, other factors – such as transport, microgreen quality control, and phytonutrient content targeting – must be considered to make a more rigorous assessment of the entire microgreen supply chain.

6.0 Industrial Projects

6.1 Research Overview

The research for this phase of the study considers a broccoli microgreen supply chain. It can be broken down into two phases: pre-harvest and post-harvest (Figure 8). The pre-harvest stage consists of production events such as the growing conditions and harvesting. The post-harvest stage consists of testing the quality of the microgreens and preparing them for distribution to various end users. Students participated in two projects that focus on the initial findings on these areas of the supply chain. Project 1 consists of developing a detailed process flow for the pre-harvest stage of a broccoli microgreen in terms of a commercial design for a microgreen supply chain. From this we are able to develop a fishbone diagram to understand the main areas of focus to improve the supply chain. Project 2 consists of developing a simulation to model the pre-harvest stage of various microgreens.

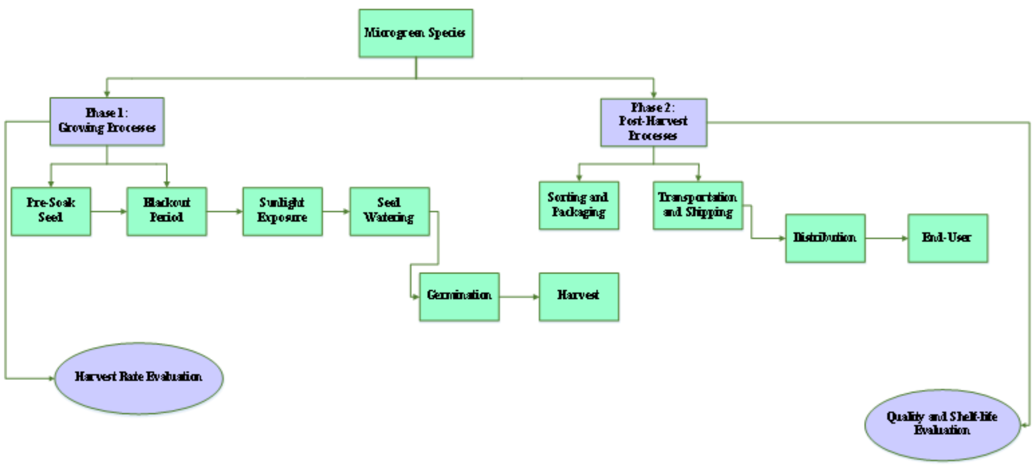


Figure 8. Pre and Post Harvest Microgreen Supply Chain Process Flow

Project 1: Broccoli Microgreen Supply Chain Analysis for the Pre-Harvest Stage

In this study, we will focus on the pre-harvest process flow that will help us determine bottlenecks in the production stage that need to be improved. To identify these bottlenecks, we use a cause-and-effect diagram (Figure 9). Using this method, we specifically focus on the pricing of microgreens. The four main factors that will be included are: transportation, manpower, advertising, and equipment.

This research aims to address some of the following questions:

1. How are transportation, manpower, advertising, and equipment affecting the profit from producing and selling microgreens?

2. What are some other factors that can affect the profit producing and selling microgreens?

The cause-and-effect diagram that has been presented demonstrates one focus area for microgreens (Figure 9).

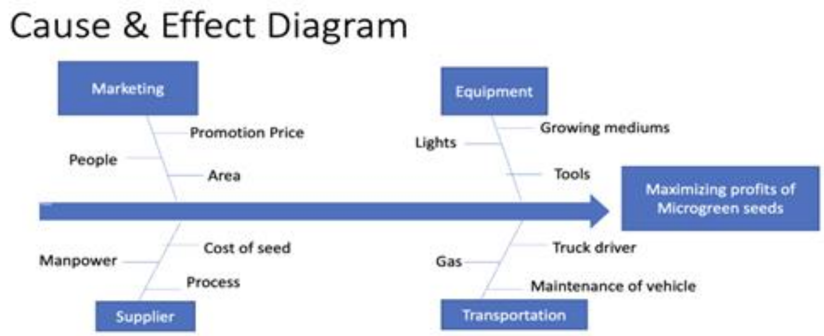


Figure 9. Cause and Effect Diagram for Maximizing Profit of Microgreens Seeds

One of the concerns that may occur with producing and selling microgreens are ways to maximize the profits of microgreens. For example, the factors that disrupt the maximum profits of producing microgreens are the equipment, marketing, suppliers, and transportation. Currently there are three different production methods that are used for growing microgreens that require different mediums. The equipment used to carry out these methods can vary in price therefore causing fluctuation in pricing of microgreens to sell. For this process the right equipment and maintenance resources must be in place to successfully grow microgreens at an optimal level to meet consumer demands. Currently, there is a high demand for healthy foods among Millennials and Gen Z. Microgreens are starting to grow in popularity among this population. It is important to develop price points that are affordable and have marketing of the benefits of this type of food to improve availability of this type of food. Transportation is another important factor to consider in terms of gas, maintenance, and quality of food. Since microgreens are a perishable food item profits can decrease as a result of delivering food products that are spoiled or rotten. Lastly, suppliers used to buy seeds at various price points and the manpower needed to grow and distribute microgreens will vary based on the supply chain design. These factors can affect profit.

6.3 Project 2: Discrete Event Simulation for a Broccoli Microgreen Supply Chain

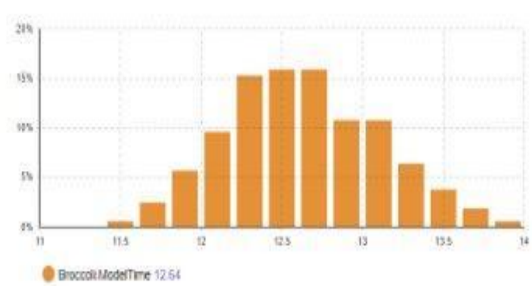
Figure 9 displays the pre-harvest stage growth processes modeled within the discrete event simulation. This consists of presoaking the seeks, black out period, sunlight exposure, seed watering, germination, and harvest. All microgreen species seeds do not need to be soaked. Pre-Soaking the seeds allows for enhanced germination [16]. A blackout period is when seeds are placed with no light before starting the growing process. Some microgreen seeds will not grow properly without this step [16]. Once the seeds are ready, different types of light quality (i.e., LED, or GDLs) are utilized. Specifically, we focus on sunlight exposure [16]. Depending on the growth medium used, a specific watering schedule would need to be followed to ensure the microgreens are watered properly. Germination refers to the seeds being covered after pre-soaked and developing a sprout before uncovered [16]. The harvest step occurs when the microgreens are fully mature and ready to be cut and used for various purposes. Broccoli, pea, beet, and buckwheat were tested under the following conditions. Each of these microgreens come from different families; Broccoli is from the Brassicaceae family [16]. This is the microgreen we focus on heavily for this research as it has cancer fighting properties. Pea comes from the Fabaceae family, which is used to treat anemia and ulcers [17]. Beet comes from the Amaranthaceae family, which has various health benefits [16]. Buckwheat comes from the Polygonaceae family, which helps with cardiovascular diseases [16].

Growing Processes

Microgreen Species	Presoak Seeds	Blackout Period	Sunlight Eposure	Seed Watering	Germination	Harvest
Broccoli	0	2-3 days	12-15 hours	1-2 times per day	3-4 days	5-7 days
Pea	12-24 hours	3-5 days	12-15 hours	1-2 times per day	2-3 days	8-12 days
Beet	8-12 hours	6-8 days	12-15 hours	1-2 times per day	1-2 days	10-12 days
Buckwheat	12 -24 hours	3-4 days	12-15 hours	1-2 times per day	3-4 days	6-12 days

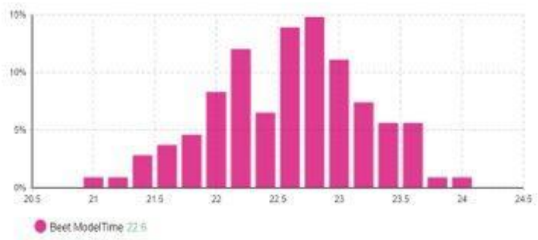
Figure 10. Modeling parameters

Figures 11a-11d show the results from running our simulation model. Since the broccoli microgreens do not require the pre-soak steps you have a shorter time to harvest than the beets or peas. This model currently does not take into consideration the shelf life.



11(a)

11(b)



11(c)

11(d)

Figures 11a-11d. Pre-harvest results for broccoli, peas, beets, and buckwheat

7.0 Conclusion

In conclusion, the research experiences allowed us to reach six undergraduate students, one postdoc and two graduate students, all from underrepresented groups. During this research experience students received training through our Agriculture Summer Professional Development Series. Each PI associated with the project shared their expertise for students to make a connection between the different fields represented. As a result, we were able to develop a new standard to test microgreens. Understand more about the target consumer and the best marketing strategies to reach them. We learned more about the effects of degradation on microgreens from retailers to consumers. We were also able to map out the processes associated with the pre-harvest stages of the supply chain. For future work we plan to test the standard and develop more robust transportation plans to reduce degradation of the microgreen supply chain to provide quality food to the end consumer.

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