

# HUMAN DIMENSIONS OF CONTROLLED ENVIRONMENT AGRICULTURE (CEA)

by

ANDREWS IDUN

(Under the Direction of Kevan W. Lamm)

## ABSTRACT

This dissertation's three articles are linked through theory and practice. Study one identifies critical issues in the controlled environment agriculture (CEA) industry using Delphi methods (Gross, 1981). Study two uses the audience segment (Grunig, 1989) as a guide to determine consumers' demographic characteristics related to their insights regarding the perceived importance of CEA critical issues. In study three, the researchers tried to understand consumers' willingness to consume CEA-grown produce using the Theory of Planned Behavior (Ajzen, 1991) as a guide. Data was collected using Qualtrics survey instruments for all three studies. However, the constant comparative method (Glaser, 1965) was used to analyze study one's data, while in studies two and three, data analysis was done using SPSS.

INDEX WORDS:     Controlled environment agriculture; sustainable agriculture; urban agriculture; critical issues; audience segmentation; theory of planned behavior

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ANDREWS IDUN

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by

ANDREWS IDUN

Major Professor: Kevan W. Lamm  
Committee: Jessica Holt  
Alexa Lamm  
Mi Hee Park

Electronic Version Approved:

Ron Walcott  
Dean of the Graduate School  
The University of Georgia  
May 2025

## DEDICATION

This dissertation is dedicated to my beloved mother, Comfort Abena Aduako, and my father, the late Emmanuel Ekow Idun, for giving me life and raising me to have the persevering mind and daring heart that have brought me this far.

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## CHAPTER 1

### INTRODUCTION

Conventional farming expansion for food security has led to deforestation, eutrophication, reduced biodiversity, and poor air and water quality (Malone & Newton, 2020; Wade et al., 2020). The global food system occupies 38% of land use, causing significant biodiversity loss (Chaudhary & Kastner, 2016). Agriculture-related human activities contribute 21-37% of annual greenhouse gas emissions (Benton et al., 2021), including land-use changes, pesticide use, food waste, pollution, and supply chain practices. Additionally, agriculture accounts for approximately 70% of global freshwater withdrawals (World Bank, 2020). “Insect populations have also declined by 75% over the past three decades, largely due to agricultural practices hampering natural breeding and fruiting processes” (Tannenbaum, 2021, p. 26).

In spite of these significant sustainability concerns, conventional agriculture practices face production constraints (Grierson et al., 2011), including “climate change and weather extremes, land degradation, the expansion of drylands, a diminishing supply of fresh water, urbanization, and increasing prices of fertilizer, fuel, pesticides and transportation” (Ampim et al., 2022, p. 1). This necessitated the introduction of the Sustainability Revolution with a focus on large-scale production while simultaneously aiming to preserve crop productivity and a healthy resource base (Congreves, 2022). However, with the various agricultural practices of the Sustainability Revolution, food production has not changed due to the industry's unaddressed issues (Congreves, 2022; Loconsole et al., 2019). Consequently, it has become imperative for producers to identify alternative strategies to satisfy global food requirements while safeguarding the environment and its natural resources (Constable, 2022). In the quest for solutions, researchers have identified that indoor farming, popularly known as controlled environment

agriculture (CEA), offers growers the opportunity to address the issues of conventional farming while improving crop productivity (Syed & Hachem, 2019).

## **1. Controlled Environment Agriculture (CEA)**

According to Dalrymple (1973), CEA production originated during the Roman Empire, and it was not until 1800 that commercial CEA food production emerged in the United States. The early CEA production was in glass houses with hotbeds of manure; however, today, in addition to the glasshouses, there are plastic-glazed houses and indoor facilities with different heating methods, most of which are manure-based (Dalrymple, 1973; Walters et al., 2020). Even though CEA systems range from high tunnels, greenhouses, and plant factories or vertical farms (Tannenbaum, 2021), the systems can be classified into soil-based examples: high tunnels, greenhouses, growing chambers, and warehouses as well as soilless cultivation, which is made up of hydroponics and aeroponics (Niu & Masabni, 2018), typically known as vertical farming. However, traditional crop production, such as mushroom, insect, and fish farming (aquaculture and aquaponics), are also known as CEA systems (Cowan et al., 2022). Additionally, the lab-grown meat method, which is at the infant stage of development, falls into the category of CEA food production (Cowan et al., 2022). High tunnels are considered the least expensive and most used CEA systems (Tannenbaum, 2021). This type of system can be constructed for as low as \$3 per square foot, requiring very little capital to start (Tannenbaum, 2021). On the other hand, greenhouses are constructed for an average of \$35 per square foot at a commercial level; because of their ability to absorb sunlight for plant activities, they are considered the most energy-efficient CEA system (Tannenbaum, 2021). Plant factories, typically known as vertical farming, are generally constructed for between \$100 and \$200 per square foot, and it is the most expensive CEA system for plant production (Tannenbaum, 2021). However, they can be

established in reclaimed buildings or containers to reduce the cost of constructing this CEA system (Tannenbaum, 2021).

## **2. Environmental Conditions of CEA**

In CEA food production, lighting, temperature, and atmospheric conditions such as humidity, ventilation, and CO<sub>2</sub> concentration are crucial to optimizing plant yield (de Carbonnel et al., 2022). “Light is vital for indoor production because of its impact on plant growth and yield” (Ampim, 2022, p. 12). The rate of plant growth, such as stem thickness, branching, and rooting, is affected by light, which plays a crucial role in photosynthesis and the development process of seed germination and flowering (McCree, 1971; Yun et al., 2017). Research shows that light-emitting diodes (LED) are more attractive in modern indoor production because the traditional light sources have a mismatch between the emitted spectrum of lighting needed to support plant growth (Yun et al., 2017). The lighting color can also support plants in achieving different objectives; for example, blue light promotes vegetative leaf development (Chowdhury et al., 2023), while red light is suitable for flowering plants.

Carbon dioxide (CO<sub>2</sub>) concentration of 1000-1200  $\mu\text{mol}$  is usually needed in indoor food production systems to increase yield and maturation (Rouphel et al., 2018). Several studies suggest that CO<sub>2</sub> enrichment in CEA systems can improve the yield of fruits and vegetables by up to 30% (Jin et al., 2009). However, according to Poudel and Dunn (2017), crops grown in CEA systems sometimes suffer suboptimal conditions caused by frequent insufficient CO<sub>2</sub> availability, limiting crop yield and quality. Because CEA systems are relatively airtight, crop CO<sub>2</sub> intake can drop to 100-250  $\mu\text{mol mol}^{-1}$  during the day, below the ambient level of 350-450  $\mu\text{mol mol}^{-1}$  with ventilation, and much lower than the optimal 800-1000  $\mu\text{mol mol}^{-1}$  needed for growth (De Pascale & Maggio, 2008; Zhang et al., 2014; Merrill et al., 2018).

Therefore, the effect of ventilation in CEA systems is very significant in plant production (Jensen, 2001; Ishii et al., 2016). CEA systems such as greenhouses rely entirely on natural ventilation, which is suitable for producing heat-resistant crops in mild climates (McCartney & Lefsrud, 2018). However, even though natural ventilation is used widely in greenhouse designs, its effectiveness depends on the availability of wind, which can change in speed and direction in the daytime, resulting in under-ventilation on warm and calm days and over-ventilate during windy days (McCartney & Lefsrud, 2018; Kumar et al., 2009). In such a situation, forced ventilation is applied to secure optimal air distribution inside CEA systems (Perone et al., 2021). Research shows that forced ventilation reduces the vertical temperature stratification in CEA systems such as greenhouses, resulting in better air distribution (Chen, 2003), and it significantly helps to control temperature, humidity, and CO<sub>2</sub> concentration (Boulard et al., 2004), which are closely linked to plant growth. It is important to note that ambient air temperature regulation significantly affects the quality of vegetable production in CEA systems (Perone et al., 2021). To achieve plant growth and yield, specific temperature ranges should be maintained; therefore, low or high temperatures outside this range can hurt plant growth and development as well as yield and quality due to nutrient and hormonal imbalances, protein misfolding, and reduced radical scavenging activity (Schonhof et al., 2007).

### **3. Benefits of CEA**

In CEA systems, producers use various media, such as peat moss, coconut husk, and fiber mat (Ampim et al., 2022) as a growing medium; therefore, considering the nutritional requirements for indoor food production, they can amend the nutrients of these substrates (Cowan et al., 2022). Supplying adequate measures of macronutrients to plants can improve the yield and product quality (Ampim et al., 2022). Using segregated CEA systems, nutrient

solutions can be recycled in a closed loop, which can help increase the efficiency of plants' absorption of nutrients (Rufi-Salís et al., 2020). Another significant advantage of the CEA systems is that regarding nutrient management, producers can easily measure and monitor the available nutrients to plants (Michael et al., 2021). According to Cowan et al. (2022), maintaining a sustainable nutritional supply through water management is economically and environmentally friendly.

The CEA systems, by design, make it possible to use a fraction of freshwater and waste fewer nutrients than conventional agriculture (Lefers et al., 2020), which helps to achieve environmental sustainability. Through these controlled conditions, CEA systems can produce a large variety of crops throughout the year, increasing the annual crop production compared to conventional farming (Wilson & Finlay, 1994; Lages Barbosa et al., 2015). Unlike conventional farming, in which rapid expansion needs large-scale land use and water, resulting in deforestation and excessive water use, the rapid expansion of CEA systems does not need large-scale land and water usage (Cowan et al., 2022), even though it can multiply food production as compared to conventional food production. The spread of pests and diseases is also decreased in CEA; therefore, pesticide use is reduced compared to conventional farming (Cowan et al., 2022). Another potential benefit of CEA systems is that food production is stable, and also because they are produced near urban centers, the amount of carbon emissions for transporting food to consumers is less than that of conventional farming (Cowan et al., 2022).

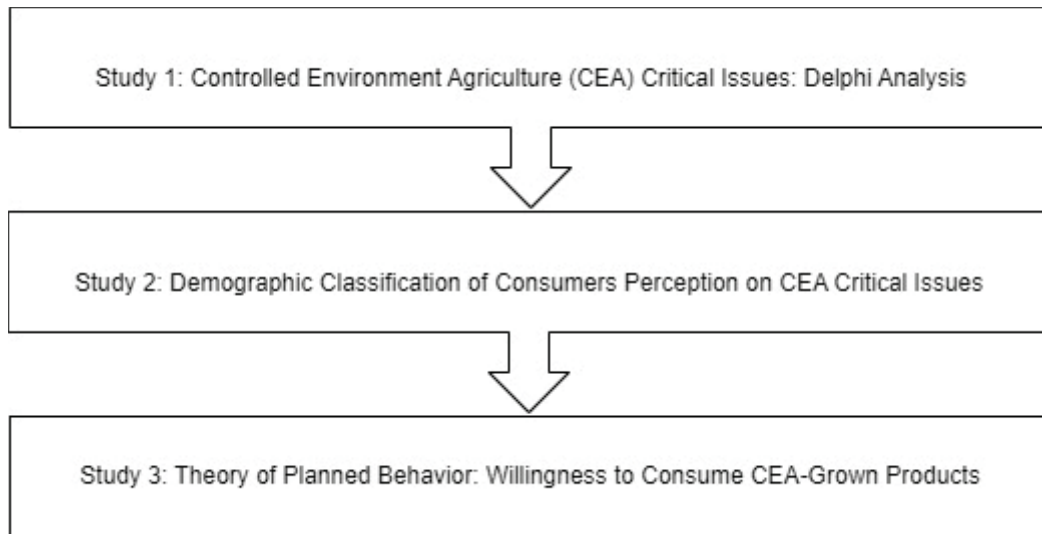
#### **4. Challenges of CEA**

Despite the potential for CEA to address many of the challenges associated with conventional food production, there are several limitations and considerations associated with CEA that remain under-examined in the literature. Creating a climate-controlled environment for

food production requires artificial lighting, heating, cooling, and, in some cases, an extra supply of CO<sub>2</sub> for geographically cold regions with restricted ventilation systems (Stanghellini et al., 2007). According to Barnes et al. (2019), these factors result in the high cost of operating CEA systems, making it difficult for most producers to adopt such technologies. Apart from the significant initial investment in physical infrastructure, operational costs remain elevated. These increased expenses contribute to higher product prices, which the consumers ultimately bear. The upward price pressures hurt demand, dampening consumers' willingness to pay for CEA products (Dieterle, 2016; Giraud, 2021). Additionally, the specialized technical skills associated with the CEA workforce compound the existing workforce pipeline and availability challenges experienced and observed across agricultural production more broadly (Lehberger & Hirschauer, 2016).

## **5. Introduction of Studies**

This dissertation, comprising three independent studies connected through theory and practice, as shown in Figure 1 below, takes a crucial step in understanding and addressing the challenges and opportunities of CEA. Study one will employ the Delphi technique to obtain consensus from experts on critical issues in controlled-environment agriculture. Study two will use cluster analysis to classify consumers' perceptions of CEA critical issues according to their demographic characteristics. Study three will seek to understand consumers' willingness to purchase and consume CEA products using the theory of planned behavior and the guide.



*Figure 1.* Overview of three proposed dissertation studies

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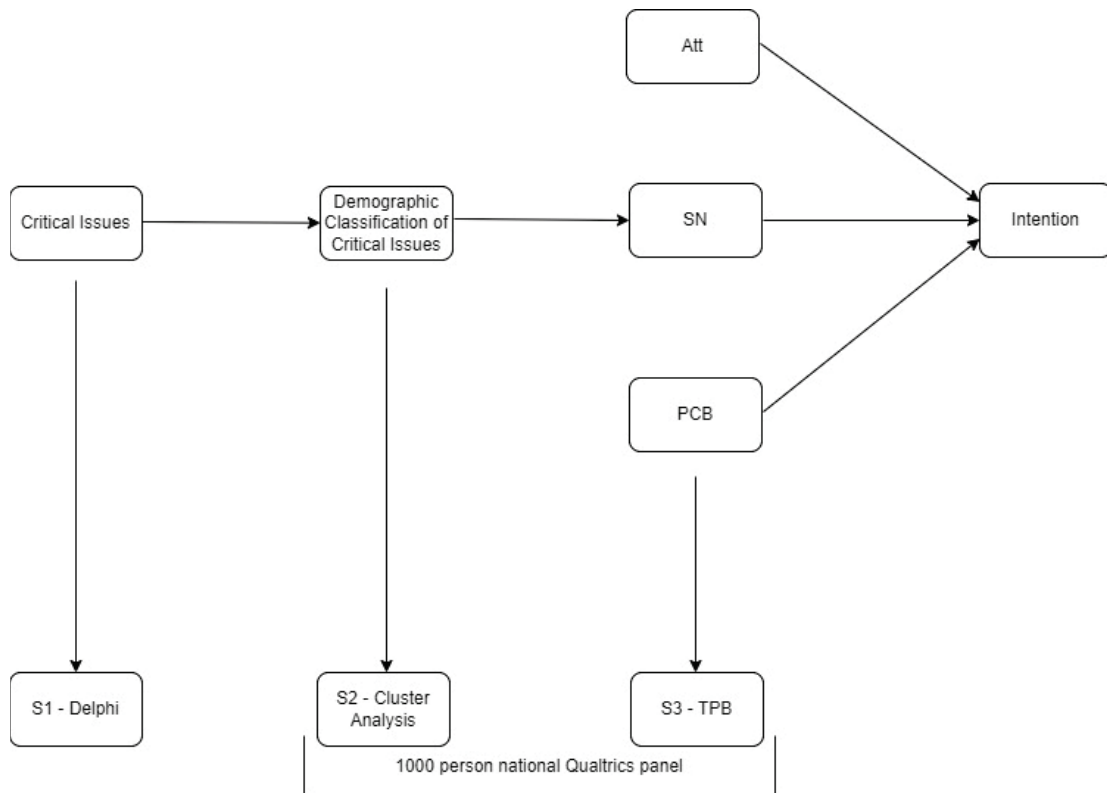
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## CHAPTER 2

### CONCEPTUAL FRAMEWORK

This dissertation aims to critically investigate the controlled environment agriculture industry, identify the most pressing issues hindering productivity and scalability, and provide recommendations for improving the industry. The dissemination will be grounded in Ajzen's (1991) theory of planned behavior and audience segments, as shown in Figure 2 below.



*Figure 2.* The conceptual framework for dissertation research

#### 1. Critical Issue in Agriculture

Agriculture faces numerous critical issues that impact food security. Key among them are climate variability, land degradation, water scarcity, diseases and pests, urbanization, technology and innovation, and labor and employment. These critical issues affect the agricultural industry,

and addressing them will require a coordinated effort by governments, researchers, producers, and other stakeholders to develop and implement sustainable agricultural practices and policies.

### *1.1. Climate Variability*

Climate variability is a significant concern for global food security. According to FAO (2015a), it threatens to reverse the progress made in the fight against hunger and malnutrition. Agricultural practices are popularly known to be a victim and potential source of climate variability (Calvin et al., 2023). Studies show that agricultural production effects on the land contribute significantly to greenhouse gas emissions (Verge et al., 2007; Snyder et al., 2009). According to Tubiello et al. (2014), the contributions of agriculture and other land use to global greenhouse gas emissions have nearly doubled and are projected to increase further by 2050. The largest share of global methane and nitrous oxide emissions, which are the products of fermentation during the digestive process of ruminants and rice cultivation, and by applying nitrogen-based fertilizers and animal manure, respectively, are all agricultural activities (FAO, 2014).

The use of fossil fuel for farm tractors and other equipment, such as harvesters, irrigation systems, and planters, in addition to activities such as the burning of crop residues, further aggravates the impact of agriculture on climate variability. In addition, livestock activities such as grazing and expanding soybean production for feeding contribute significantly to climate variability (Steinfeld et al., 2006). The climate variability feedback loop affects agricultural production in several ways, both directly and indirectly. The direct effects are seen in the modification of physical characteristics, such as temperature levels and rainfall distribution, while the indirect effects affect production due to changes in species, such as pollinators, pests, disease vectors, and invasive species (FAO, 2015a, p. xi). These factors affect agriculture

through higher temperatures, increases in carbon dioxide concentrations, weeds, pests, diseases, precipitation, and the frequency of droughts and floods, reducing yields (FAO, 2017a). Climate variability also significantly affects livestock production through animal productivity, health, and yields of forages and feed crops (FAO, 2015a). However, controlled environment agriculture (CEA), which is considered a resilient method for growing crops amid climate variability, such as extreme temperatures, floods, and droughts (Agritecture & WayBeyond, 2021), is a backup technology to address future resource consumption and agricultural environmental challenges (Despommier, 2011).

### *1.2. Land Degradation*

According to Jones and Montanarella (2003), land degradation occurs when resources are reduced due to one or more factors, such as erosion caused by wind or water, degradation of the soil's physical, chemical, biological, or economic properties, and deterioration of natural vegetation over time. FAO (n.d.) explained that the global natural resource base has shown signs of degradation, with 15 out of 24 ecosystem services being degraded or used unsustainably. In addition, actions by the food system to intensify production to meet the growing food demand by 2050 have further exacerbated land degradation, causing soil nutrient depletion, erosion, desertification, depletion of freshwater reserves, and loss of tropical forest and biodiversity. Steinfeld et al. (2006) suggest that land degradation caused by agriculture, in turn, leads to reduced productivity.

However, it is important to note that, besides reducing food production and security, land degradation further impedes agricultural income and economic development (Scherr & Yadav, 1996; Steinfeld et al., 2006). Studies show that in Africa, soil erosion depressed yields by 2 to 40 percent, resulting in a loss of 8.2 percent for the continent (Lal, 1995), while 75 billion tonnes of

soil were estimated to be lost annually, costing approximately US\$400 billion per year, or about US\$70 per person per year (Lal, 1998). Analysis conducted by the International Food Policy Research Institute (IFPRI) (Scherr & Yadav, 1996) suggested that a slight increase in land degradation compared to then-current trends may have led to a 17–30 percent increase in global prices of essential food commodities by 2020, as well as an increase in child malnutrition. These externalities of environmental degradation because of conventional agriculture can be avoided by adopting controlled environment agriculture (Tannenbaum, 2021). This is because studies show that adopting CEA systems can reduce and improve agricultural land use (Kalantari et al., 2018).

### *1.3. Water Scarcity*

Even though sufficient freshwater resources exist globally to enable continued agricultural and industrial development, they are scarce when their demand exceeds the available amount at the current price or given current access conditions (FAO, 2015). The FAO (2017a) report indicates that water usage has almost doubled the population growth rate in the last century, increasing the water demand (FAO, 2017a). This has resulted in agriculture competing with other industries for water (FAO, 2017b), even though it accounts for 70 percent of global freshwater withdrawals (FAO, 2015) and with the global need for an increase in food production to meet food security by 2050, agriculture production needs to find alternative ways of meeting its water demands. As such, some producers resort to groundwater for agriculture purposes, and as the withdrawal rate increases, exceeding the rate of natural recharge, it becomes unsustainable, threatening the ecosystems and even making the water scarcity situation even worse in some regions (FAO, 2017b). Besides groundwater depletion due to excessive withdrawals, there is a growing concern about salinization. Studies show that salt contamination of the aquifers and rivers can negatively affect the quality of water (Cañedo-Argüelles et al.,

2013; Vengosh, 2014), making it unsafe for agricultural purposes. Nevertheless, it is important to note that the water requirements of conventional agricultural methods are very different from CEA food production (Cowan et al., 2022). CEA systems use a fraction of freshwater than that of conventional agriculture (Lefers et al., 2020). CEA systems such as hydroponic and vertical farms have been identified to save up to 99% of the water required to grow some types of crops (Benke & Tomkins, 2017; Kalantari et al., 2018). Recycling wastewater for use in CEA systems is also made possible (Ellingsen & Despommier, 2008), further improving the efficiency of water usage.

#### *1.4. Disease and Pests*

There is a growing concern about the increase in the number of outbreaks of transboundary pests and diseases affecting plants and animals (FAO, 2017a). As FAO (2017a) noted, this severely threatens the affected area's food security, economics, social and environmental conditions, and beyond. A study by Lamm and Lombardini (2021) identified pest and disease management as one of the top issues in the horticulture industry. According to them, emerging pests and pathogens resist current pest management practices, making it difficult for farmers to control them. This situation is even more alarming with the spread of such outbreaks in the broader location, which is further increased by the movement of people, animals, and agricultural products within and between countries (FAO, 2017a), making it difficult to predict and provide appropriate response to contain the impact. However, in CEA, the exposure to the spread of pests and diseases is decreased, resulting in reduced pesticide use compared to conventional agriculture practices (Cowan et al., 2022). Additionally, CEA farmers are known to use technologies to detect early signs of pest infestations or diseases, allowing them to act

quickly and effectively to solve the issue, saving cost that comes with pest and disease infestations in their farms (Agritecture & CEAg, 2024).

### *1.5. Urbanization*

Urbanization influences food demand and consumption patterns (Steinfeld et al., 2006; FAO, 2017b). According to FAO (2017b), higher urban income and wages tend to increase the demand for processed foods, animal-sourced foods, fruits, and vegetables, as well as the opportunity cost of preparing food. These consumption patterns contribute to the shift in employment within the food system, resulting in fewer work opportunities in agricultural industries and encouraging more transportation, food processing, wholesaling, retailing, and vending (Cohen & Garrett, 2009). As noted by FAO (2017b), the changes in the agricultural industry, especially the technical progress and the adoption of labor-saving technologies, contribute to increasing urbanization; however, agriculture and the food industries will likely continue to be affected by urbanization. Due to the inadequacy of conventional farming methods in addressing this issue, controlled environment agriculture (CEA), represented by sustainable intensification (Pretty, 2018), is viewed as the strategic approach to overcoming the challenges associated with urbanization (Tan et al., 2022). For instance, CEA systems like vertical farms are noted for their transformation potential in urban food production (Akintuyi, 2024).

### *1.6. Labor and Employment*

Labor challenges are a big concern in the agricultural industry. There has been a shortage of skilled and manual workers (Lamm & Lombardini, 2021), making it difficult for growers to keep pace with the growing demand for food production. However, studies show that there is a decline in agricultural degree programs as well as enrollment in the few programs that offer the knowledge and skills for employment needs in the agricultural industry to address the industry's

challenges (Brevik et al., 2020; Hansen et al., 2007; Repinski et al., 2011; Royal Society of Chemistry, 2013). Therefore, stakeholders need an intentional approach to make available opportunities that help prepare the workforce to meet the needs of the agricultural industry before they start work and the opportunities for professional development for workers in the agricultural industry (Lamm & Lombardini, 2021). In addition, infrastructure investments in the agricultural industry can provide positive returns and create employment opportunities in the agricultural sector (FAO, 2017b). For instance, even though the labor force requirement in conventional agriculture is not needed under controlled environment agriculture (Ragaveena et al., 2021), investing in the CEA industry can create new careers, such as consulting engineers, software engineers, technologists, project managers, maintenance workers, and marketing and retail professionals (Benke & Tomkins, 2017; Despommier, 2010).

### *1.7. Technology and Innovation*

A study by Lamm and Lombardini (2021) revealed that the agricultural industry faces production challenges and lacks innovations to address the need for sustainable practices and increased productivity. They, therefore, emphasized the need for growers to embrace technology and precision agriculture and adapt to the changing demographics and associated consumer preferences. As a result, the scope of technological options should be expanded, and farming systems that utilize improved technologies should consider conserving water and labor, reducing loss and waste, and managing natural resources (FAO, n.d.). This is because it is undoubtedly true that resource-conserving practices such as conservation and climate-smart agriculture increase agricultural productivity (FAO, 2017b), even though they emphasize the use of environmentally friendly practices. Therefore, technologies that promise win-win combinations of enhancing productivity and sustainability in managing natural resources, such as conservation

and climate-smart agriculture, should be encouraged (FAO, 2017b). Fortunately, controlled environment agriculture (CEA) technology is poised to significantly impact the food production system and address the increasing global shortage of high-quality and affordable food products (Tannenbaum, 2021). Over time, CEA has heavily relied on contemporary agricultural technology due to extensive development and practice (Tan et al., 2021), allowing growers to use significantly less water and fertilizer than conventional agriculture (Tannenbaum, 2021).

## **2. Theory of Planned Behavior and Agriculture**

The theory of planned behavior (TPB) explains how individuals' attitude, behavioral control, and subjective norms influence behavioral intention, where the intention is considered a mediating predictor of behavior. Ajzen (1991) claimed that the impact of possible relevant background variables such as personal characteristics and experience should be examined to enhance the prediction of human intentions. This theory has been widely implemented in various disciplines to explain an individual's motivation and associated behaviors. More recently, several studies added variables to the original TPB framework in agricultural training contexts, highlighting the relationship between farmers' attitudes, subjective norms, perceived behavioral control, and their behavioral intention to apply their knowledge and education to more environmentally friendly approaches for their farming (Bagheri et al., 2019).

### *2.1. The Core Components of TPB*

The notable core components in TPB are attitude, subjective norm, and perceived behavioral control. These components have contributed a lot to shaping the behavior of individuals. As suggested by Al-Swidi et al. (2014), "the focal point of TPB is the individuals' intention to engage in a certain behavior" (p. 2). Therefore, when these components favor a specific behavior, they promote the intention to carry it out. According to Wang et al. (2021),

individual behavior can be predicted to some extent by their behavior intention, which in turn depends on individual attitudes and subjective norms and perceived behavioral control.

It is important to emphasize that among the components, the attitude toward a specific behavior refers to the perception of that behavior's positive and negative outcomes. In many instances, a person's attitude toward performing a behavior has proven to be a powerful predictor of their intention to perform that behavior. Based on Ajzen and Gilbert Cote's (2008) work, attitude was the most reliable predictor of individual intentions. Several studies have confirmed this conclusion, asserting that attitudes influence the intention of an individual to perform a particular action (Karimi et al., 2014; Robledo et al., 2015). In this context, individuals who rate a behavior positively will be more inclined to perform that behavior if they have a favorable opinion.

On the other hand, subjective norm refers to the social pressure to engage in or refrain from engaging in specific behaviors. Examining this variable reveals how individuals think others would perceive their actions. A study by Xu et al. (2018) found that if people expect individuals to make decisions, they are more likely to believe that the decision is feasible. This suggests that individuals' decision-making is influenced by their family, relatives, and friends. Additionally, the TPB was more predictive when subjective norms were applied. Studies have shown that subjective norms of society may influence individuals' willingness to start a new business (Nguyen, 2021; Arunrat et al., 2017). A similar position is advanced by Zhou et al. (2016), who argue that social pressure increases people's awareness and strengthens their intention to fructify a new activity. This suggests that social norms have a significant effect on the behavior of individuals, and the degree to which they perceive social pressure can influence the behavior of individuals and can have a significant impact on the way they achieve success.

Another factor known to influence the process of intention by the individual is perceived behavioral control (PBC). PBC can indirectly and directly affect a person's behavioral intention. As Taylor and Todd (1995) point out, a positive correlation exists between perceived behavior control and behavior intention. Farrell et al. (2016) also noted that perceptions of behavior control play an essential role in decision-making. Several studies have demonstrated that perceived behavioral control impacts behavior intention (Iakovleva et al., 2011; Kautonen et al., 2013). How an individual perceives internal and external pressures about a particular behavior affects how that behavior is performed. The relationship between attitude, subjective norm, and intention is influenced by perceived behavioral control in TPB. As a result, an individual's perceptions regarding how complex or straightforward a behavior will be to perform and the likelihood of success will shape their intention to perform the behavior. In TPB, any behavior requires some level of planning so that one's intentions can be predicted. Despite this, TPB effectively predicts behavior and provides a framework for facilitating behavior change (Chase, 2015).

## *2.2. TPB in the Agricultural Industry*

A study by Bagheri et al. (2019) found that acquiring relevant knowledge was the most critical variable influencing all TPB constructs for farmers' behavioral intention to use pesticides. However, Despotović et al. (2019) reported that farmers' environmental knowledge and education level do not significantly impact their intention to adopt integrated pest management practices. Bagheri et al. (2019) also used TPB to understand farmers' behavioral intention to learn safety information. They identified that only subjective norms and perceived behavioral control among the TPB constructs positively influenced participants' intentions. In a study that examined the different factors affecting smallholder farmers' intention to adopt and their

adoption behavior toward climate-smart agriculture. It was found that farmers' attitudes had a positive impact on their intention to adopt climate-smart agriculture practices but had no direct impact on their actual adoption behavior (Atta-Aidoo et al., 2022). Additionally, subjective norm did not impact farmers' intention to adopt climate-smart agricultural practices but significantly impacted farmers' actual adoption of CSA practices. They further stated that perceived behavioral control significantly impacted farmers' intention to adopt actual CSA practices.

Doran et al. (2020) investigated the factors associated with farmers' intention to implement nutrient management practices. They found that perceived behavioral control had the most positive influence on farmer intention, and their educational background also positively influenced their intention to adopt nutrient management best practices. Xue et al. (2021) also studied farm households to measure farmers' perceptions of agricultural mulch film pollution based on TPB. The authors found that farmers' attitudes, subjective norms, and perceived behavioral control were all associated with farmers' perceptions. However, farmers believed that agricultural mulch films could pollute the environment, so they did not change their behavior. In a study to identify the behavioral factors that influence the acceptance of AI systems in agriculture based on the integration of TAM and TPB, and two additional factors such as expectation of ownership of business data and personal innovativeness, it was noted that perceived behavioral control and attitude of farmers were the most important factors that influence the acceptance of AI in agriculture (Mohr & Köhl, 2021).

Alavion et al. (2017) sought to determine how attitudes, subjective norms, and perceived behavioral control predict the intention of agricultural services professionals working in both public and private sectors to adopt e-marketing of agricultural commodities. The study identified that attitude, subjective norms, and perceived behavior control were all positive factors in

predicting the intention to adopt e-marketing. Hansson et al. (2012), in their study using TPB to explain the underlying psychological constructs that influence farmers' decisions to involve their businesses in ventures outside conventional agricultural production, identified subjective norms and attitudes that significantly influence farmers' decision-making.

Bhujel and Joshi (2023) studied the behavioral factors influencing farmers' intention to adopt sustainable agricultural practices. They uncovered how attitudes, environmental consciousness, subjective norms, knowledge, and perceived behavioral control interact. The study identified the roles of environmental consciousness, knowledge, perceived behavioral control, and subjective norms in shaping farmers' attitudes and intentions toward sustainable agriculture.

Badsar et al. (2023) examined the agricultural sustainable environment behavior and behavioral intention of farmers in agriculture activities using the protection motivation theory (PMT) and the theory of planned behavior (TPB). The study confirmed the applicability of integrating the two theoretical models in predicting farmers' sustainable environmental behavior and behavioral intention – thus providing strong evidence supporting the integration of both models in better understanding the factors influencing farmers' sustainable environmental behavior and behavioral intention. Based on the study, they identified that self-efficacy instead of perceived behavioral control not only had a significant effect on farmers' behavior intention but also had significant direct effects on farmers' sustainable environmental behavior.

### *2.3. TPB in Horticulture*

A study describing nursery growers' behavioral intent to use automated nursery technologies identified intent as negative but close to neutral, suggesting that growers were not overly likely to adopt even though these technologies have the potential to help solve the

industry's labor issues (Warner et al., 2022). In addition, the study's findings included overall positive attitudes and nearly neutral but positive perceived behavioral control and perceptions of adopting automated nursery technologies, explaining variability in intent to adopt automated nursery technologies among growers. However, in the attempt to understand the factors affecting the internet behavior of horticultural growers, it was identified that the attitudes of business managers were the primary influence on internet usage (Taragola & Van Lierde, 2010). According to them, managers who demonstrate open communication and actively seek information are most likely to use the Internet to get the necessary information.

Moons et al. (2022), in a study investigating the drivers and barriers to adopting sustainable and innovative solutions by horticultural greenhouse growers, also identified attitude towards innovation as the main predictor of adoption intention. They noted that the relative advantages of sustainable, innovative solutions mainly drove attitude. However, trialability and observability were important factors that growers considered when adopting innovation. Regarding perceived behavioral control, the study identified that some growers felt less able to get involved in innovation due to their age or personal or financial status.

### **3. Demography and Smart Farming Adoption**

Despite the prevalence of smart farming worldwide, conventional farming remains more common (Rambo, 2017). This has resulted in low-quality and low-margin yields, which call for a shift from conventional to smart farming (Saengavut & Jirasatthumb, 2021). Smart farming is a new type of farming method that uses different technologies and innovations with high accuracy to improve farming practices by prioritizing the consumer's safety and the environment and the most cost-effective use of resources (Jayashankar et al., 2018). Studies show that demographic

characteristics such as gender, age, and educational level of farmers will likely influence the probability of adopting new technologies (Akudugu et al., 2012).

### *3.1. Age*

It is important to note that farmers' adoption of technology is strongly influenced by the age of the household head (Phuensane et al., 2022). According to Mignouna et al. (2011), age is assumed to be a determinant factor in adopting new technology. As farmers age, they gain knowledge and experience over time, making them better able to evaluate the importance of a new technology than younger farmers (Phuensane et al., 2022). However, on the contrary, Phuensane et al. (2022) suggest that there is another finding that age negatively influences the adoption behavior of farmers. Studies show younger farmers are less risk-averse and more willing to try new technologies than older farmers (Adesina & Zinnah, 1993; Mauceri et al., 2004). This is because when they grow older, there is the possibility of an increase in risk aversion and a decrease in interest in long-term investment in their farm (Phuensane et al., 2022).

### *3.2. Gender*

The gender of the household head is found to influence the adoption of new technologies negatively (Asfaw et al., 2012). A study by Phuensane et al. (2022) identified that if the household head is identified as male, the chance of adopting new technology decreases in wheat product packaging. However, on the contrary, some studies have found that male-headed households are more likely to adopt improved wheat varieties than female-headed households (Kebede et al., 2017; Doss & Morris, 2000). According to Phuensane et al. (2022), male-headed households adopt the improved varieties more than their female counterparts because they have relatively better access to information and agricultural resources than female household heads.

Additionally, they noted that male households have access to information, which makes it easier for them to use new technologies and innovation than female-headed households.

### *3.3. Educational Level*

The educational status of the household head is known to be the most common and significant variable influencing farmers' adoption behavior (Phuensane et al., 2022). Studies show a significant favorable influence on the adoption of technologies and farmers' educational levels. As Mulugeta (2012) noted, educated farmers can better process information and search for appropriate technologies to alleviate their production constraints. Phuensane et al. (2022) also identified in a study that farmers' different educational levels result in different adoptions of Smart Farming.

### *3.4. Income Level*

According to Dissanayake et al. (2022), several authors have cited income levels as a contributing factor influencing adoption. Current studies show that adopting sustainable agricultural technologies requires sufficient financial support (Priya & Singh, 2024). This finding confirms previous studies revealing that farmers' different income levels significantly influence their adoption of smart farming (Phuensane et al., 2022; Melesse, 2018). Even though the increase in farmers' income from their in-farm is found to be associated with technology adoption (Lambert et al., 2015), Yatribi (2020) noted that access to off-farm income-generation activities contributes to technology adoption. A similar study by Barnes et al. (2019) suggests that off-farm income-generation opportunities contribute to moderate-income farmers acquiring new technologies.

#### **4. Demography as Variables in TPB**

In a study conducted by Botetzagias et al. (2015) to examine whether TPB may be enhanced by the introduction of moral norms and demographic variables as further predictors of recycling intention (RI), it was noted that the overall demographic variables were statistically non-significant predictors of RI, except for gender whose total effect was minimal. In an extended theory of planned behavior to explain the intention to use car sharing, Li and Zhang (2023) noted a significant moderating effect of gender between subjective norm and behavioral intention to use car sharing. They also identified that subjective norms influence females' intention to use car sharing more strongly than males, which suggests that women's intentions to use car sharing are more susceptible to social influence. However, the study proposed that those who have confidence in their driving skills or have a lot of driving experience are more likely to use car sharing. Therefore, since men are generally known to be more confident in their driving skills than women (D'ambrosio et al., 2008), males are more likely to use car sharing. Additionally, the relationship between perceived behavioral control and the intention to use carsharing was found to be moderated by car ownership and gender but not by age or income.

Moon (2021) used TPB as a theoretical framework and extended it with two additional predictors, past behavior and dining frequency, and gender and age as moderators to identify consumer belief structures underlying the cognitive process of green restaurant patronage. The results showed that all relationships between the original constructs of the TPB were significant, indicating that the TPB is a valid model in the Green Restaurant context. The moderating effects of gender and age were also confirmed. In a longitudinal study conducted by Morris et al. (2005) on gender and age differences in employee decisions about new technology using the theory of planned behavior as the framework, they found that, as a predictor of intention in the short run,

men were more influenced by instrumentality, while social factors and environmental constraints more strongly influenced women. However, there were no significant gender differences in the determinants of technology use. The study indicated that while TPB helps explain technology adoption and use in organizations, extending the theory to include the combined moderating effects of gender and age significantly increases the understanding of the underlying phenomenon. Additionally, the study indicated that the pattern of gender differences in individual technology adoption varies with age, such that gender differences are more pronounced with increasing age.

The effects of gender and age on new technology implementation were also tested using the planned behavior by White Baker et al. (2007). The study identified that age and gender as moderating variables on attitude, subjective norm, and perceived behavioral control as they affect behavioral intention to use technology was non-significant. However, most study participants were relatively young and homogeneous, so the findings were unexpected. Additionally, from the perspective of gender, the lack of any moderating influence was surprising since the women in the study were small in proportion as compared with their male counterparts.

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CHAPTER 3  
CONTROLLED ENVIRONMENT AGRICULTURE (CEA) CRITICAL ISSUES: DELPHI  
ANALYSIS<sup>1</sup>

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<sup>1</sup> Idun, A., Lamm, K. W., Holt, J., Lamm, A.J., & Park, M. To be submitted to *Horticulturae*.

## **Abstract**

Expanding and intensifying conventional farming to ensure global food security has led to several challenges. Even with the various agricultural practices of the Sustainability Revolution, food production has not changed due to the industry's unaddressed issues. In the quest for answers, researchers found that indoor farming, popularly known as controlled environment agriculture (CEA), offers the opportunity to increase food production while saving the environment. However, despite the potential for CEA to address many of the challenges associated with conventional food production, several limitations and considerations exist regarding CEA systems that need to be addressed by stakeholders to encourage growers to adopt the innovation. Therefore, the study, conducted in collaboration with an expert panel composed of agricultural faculty members, compiled a comprehensive list of critical issues facing the controlled environment agricultural industry using a Delphi methodology. Using a three-round consensus-building process, 30 critical issues were identified, with seven items receiving 100% agreement among the panelists. The final list of items was then analyzed using the constant comparative method to identify themes within the retained items. Eight themes emerged based on the analysis, including (alphabetically) disease and pests, energy, economic considerations, food safety and quality, market dynamics, operation and infrastructure, startup capital, and workforce. The proposed themes and subsumed critical issues represent a heuristic framework to facilitate dialogue amongst the stakeholders in the controlled environment agricultural industry about the industry's future and progress and for research purposes.

## 1. Introduction

Studies indicate that expanding and intensifying conventional farming to ensure global food security has led to deforestation, eutrophication, decreased biodiversity, and poor air and water quality (Malone & Newton, 2020; Wade et al., 2020). Globally, the food system accounts for 38% of land use and is the leading cause of global biodiversity loss (Roser & Ritchie, 2013). In addition, approximately 70% of the global freshwater withdrawal is from agriculture (World Bank, 2020). Insect populations have declined 75% over the past three decades due to agricultural practices that hinder natural breeding and fruiting processes (Tannenbaum, 2021).

Despite these significant sustainability issues, conventional agriculture practices also face production constraints (Grierson et al., 2011), such as climate change, extreme weather events, land degradation, the expansion of drylands, declining freshwater availability, urban growth, and rising costs for fertilizers, fuel, pesticides, and transportation (Ampim et al., 2022). It was determined that this would require the implementation of the Sustainable Revolution, which would focus on large-scale production while preserving crop productivity and a healthy resource base (Congreves, 2022). Even though new farming methods were introduced during the Sustainability Revolution, food production has remained the same because problems in the industry have not been fixed (Congreves, 2022; Loconsole et al., 2019). It has, therefore, become necessary for growers to find alternative approaches to meet global food demands while preserving the environment and its natural resources (Constable, 2022), and controlled environment agriculture (CEA) is identified to serve that purpose (Syed & Hachem, 2019).

However, although CEA has the potential to address many of the challenges associated with conventional food production, several limitations exist regarding CEA systems. According to Dinnie and MacLean (2022), CEA is generally considered an expensive agricultural practice.

Apart from the high initial costs for physical infrastructure (Dieterle, 2016; Giraud, 2021), there is a high operation cost due to the created climate-controlled environment for food production (Stanghellini et al., 2007). This contributes to the increased costs of products, dampening consumers' willingness to pay for CEA products and discouraging farmers from adopting such innovations in agriculture (Barnes et al., 2019). Additionally, the specialized technical skills associated with the CEA workforce compound the existing workforce pipeline, and the availability challenges experienced and observed across agricultural production more broadly (Lehberger & Hirschauer, 2016) have made it difficult for CEA growers to meet their labor needs. Therefore, the proposed study examines experts' perspectives on critical issues in controlled-environment agriculture to identify and further examine the nexus of opportunities and challenges.

### *1.3. Study Framework*

The present study utilized Consensus building theory (Innes & Booher, 1999) to develop a more robust representation of CEA production. The consensus-building theory is an approach that requires key stakeholders within a particular group to come together in good faith to reach an agreement (Consensus building, n.d.) about a phenomenon of concern. According to Burgess and Spangler (2016), this theory has been applied across various uncertain, complex, and controversial planning and policy tasks. A study by Lamm et al. (2023) used consensus building and opinion leadership to identify critical issues facing Georgia's Agriculture, Forestry, and Natural Resources Industries. Using the consensus-building theory, the researchers will be able to identify the range of issues facing CEA, which remains a noteworthy gap within the literature.

#### *1.4. Study Purpose*

This study, informed by the following research objectives, aimed to identify critical issues facing the controlled environment agriculture industry. The research objectives were to:

1. Create a comprehensive list of potential critical issues facing the controlled environment agriculture industry.
2. Generate a consensus on the specific critical issues facing the controlled environment agriculture industry.
3. Develop a heuristic thematic grouping of critical issues facing the controlled environment agriculture industry.

## **2. Materials and Methods**

### *2.1. Delphi Technique*

This study used the Delphi technique to collect and analyze data intended to establish consensus amongst a panel of experts (Lamm et al., 2023). According to Gross (1981), this technique, developed in the early 1950s by the RAND Corporation, was used to predict the future effect of technology on warfare. Since then, the Delphi technique has had many applications in social science research. Cyphert and Gant (1971) noted that the Delphi technique was used in 1971 to gather opinions from individuals without physically bringing them together. Lamm et al. (2023) used this technique to bring together “emerging or established leaders within the state agricultural and forestry industries in Georgia” (p. 2) to help identify critical issues facing the agriculture, forestry, and natural resources industries in Georgia. Using the Delphi technique, the researcher can encourage freedom from conformity and pressures and enable participants to thoroughly deliberate and reflect upon all aspects of the problem to generate, review, and rank ideas, enhancing the quality of the findings (Altschuld, 1995).

## *2.2. Expert Panel*

As described by Lamm et al. (2023), the Delphi study follows a specific process, such as developing the initial Delphi questionnaire with a clear purpose, identifying experts interested in participating in the study, and then determining the number of participants. Therefore, for this study, the advisory board members and project team members of the “Green-Reimagining of Agriculture in Controlled Environments” – GRACE Project were selected as the experts for the study. The GRACE Project is a NIFA-USDA-funded project whose goal is to strategically, managerially, technologically, and socially transform CEA to position it as a viable food production system capable of producing sufficient and nutritious foods within the low-carbon economy. Therefore, since the study is in connection with the grant, the 17 investigators of the grant were identified and invited to participate as the experts in the three-round stages of the Delphi study. These experts were identified based on their role on the grant advisory board. They also serve as faculty members in their respective institutions.

## *2.3. Data Collection and Analysis*

Based on the prescribed methodology specifying the Delphi study's implementation procedures (Van de Ven & Delbecq, 1974) and previous Delphi studies on critical issues facing the agriculture, forestry, and natural resource industries in the State of Georgia (Lamm et al., 2023), this study instrument was developed. In the first round, the panelists were asked to respond to an online survey, in which they were asked to use a word or short description to describe up to five top critical issues facing the controlled environment agricultural industry. There were 17 responses, representing a 100% response rate. A total of 71 critical issues were identified. These 71 critical issues were then cleaned of duplicated responses (Garson, 2014),

resulting in 55 unique issues. The results from the first round of the process were used to develop the second-round survey and send it to the panelists.

In the second round of the process, the participants were asked to indicate their level of agreement or disagreement with each identified critical issue from the first round using a five-point Likert-type scale ranging from 1—Not at all important to 5—Extremely important through an online questionnaire. After the second round, the data received was analyzed using the SPSS v26 software package, and the mean score for retention of 3.5 was established a posteriori, with a total of 55 items retained and presented for the third round of the process.

The third and final round was also conducted using an online questionnaire. The final survey asked participants whether each issue should be retained or not using a dichotomous yes or no variable. A minimum level of consensus was established at 80% a posteriori. At this point, the panel agreed on 30 specific critical issues facing the controlled environment agricultural industry. A total of 13 items achieved a consensus between 94% and 100%, with 7 of those items achieving 100% consensus and the rest of the 17 items achieving between 81% and 88% consensus.

In the final stage of the study, the retained issues were thematically analyzed using the constant comparative method (Glaser, 1965). According to Lamm et al. (2023), this method generally allows researchers to generate “a heuristic thematic grouping of items through repeated comparison” (p. 4). The data was reviewed and coded into categories for analysis at the initial stage, and the themes that emerged through repeated coding and comparison were recorded. In the recorded themes, higher-order categories emerged through repeated comparisons (Glaser, 1965). The research team employed peer debriefing and member checking to improve the trustworthiness of the analysis and reduce bias (Glaser, 1965; Lincoln & Guba, 1985).

### 3. Results

In the first round, the study produced 71 responses that were consolidated into 55 unique issues, as shown in Table 1 below. This list of 55 responses was then presented to the panel in the second round of the Delphi process. The means for the critical issues provided in the second round ranged from 1.004 to 4.88, with profitability gaining the highest level of agreement, followed by the cost of production. The remaining critical issues that followed in order of agreement were energy costs, energy demands, labor costs, labor availability, energy management, quality of product, cost of effectiveness, greenhouse environment management, initial capital investment, and sales price of crops. After the second round of analysis, 42 items were retained out of the 55.

**Table 1.**

*Delphi round one and two results: level of critical issues facing the controlled environment agricultural industry (1 = least important; 5 = most important) (n = 55).*

Issue	1	2	3	4	5	Mean
Profitability	0	0	0	2	15	4.88
Cost of production	0	0	0	3	14	4.82
Energy costs	0	0	1	4	12	4.65
Energy demands	0	0	2	4	11	4.53
Labor costs	0	0	1	8	8	4.41
Labor availability	0	0	1	8	8	4.41
Energy management	0	1	2	3	11	4.41
Quality of product	0	1	2	4	10	4.35
Cost effectiveness	1	0	1	5	10	4.35
Greenhouse environmental management	0	1	0	8	8	4.35
The initial capital investment	0	2	1	3	10	4.31
Sales price of crops	0	1	1	7	8	4.29
High energy consumption	0	1	2	6	8	4.24
Controlling pests	1	2	1	2	11	4.18
More energy efficient equipment needed	0	2	2	5	8	4.12
Unit economics	0	1	4	4	8	4.12
Production cost	0	0	3	9	5	4.12
Cost for maintenance	0	1	2	8	6	4.12
Dealing with pathogens	1	2	2	2	10	4.06
Growing the right crops for market demand	0	2	3	4	8	4.06

Food safety	0	4	0	4	9	4.06
Finding markets (region specific)	0	3	1	5	8	4.06
Marketability	1	0	4	5	7	4.00
High input cost compared to traditional production	0	1	4	6	6	4.00
Access to funds to get started	0	2	3	5	7	4.00
Disease management	1	2	2	3	9	4.00
Environmental control – HVAC	0	2	2	8	5	3.94
Crop selection	0	3	1	7	6	3.94
High infrastructure cost	0	2	2	8	5	3.94
Learning of the system	0	2	3	7	5	3.88
The high cost of non-sustainable energy resources	0	3	2	8	4	3.76
Cost for improvement	0	1	7	4	5	3.76
Lack of trained workers	1	3	1	7	5	3.71
Identifying the right model	1	3	2	5	6	3.71
Lack of sound economic analyses	0	1	8	3	5	3.71
Import competition	0	5	2	4	6	3.65
Pathogen pressure	1	2	4	5	5	3.65
Lack of relevant workforce development program	1	3	2	7	4	3.59
Marketing	1	3	3	5	5	3.59
Limited R&D capacities	1	4	3	3	6	3.53
Dependency on technology	0	3	5	6	3	3.53
Market competition	1	1	6	6	3	3.53
Government policy	1	2	5	6	3	3.47
Capital raising	1	3	4	5	4	3.47
Limited means to control pests and diseases	1	3	5	3	5	3.47
Better cultivation techniques	0	4	6	3	4	3.41
Technical and training support from Land Grant Universities	3	0	5	6	3	3.35
Lack of proven implemented systems in the USA	0	5	5	3	4	3.35
Water reclamation	1	6	1	5	4	3.29
Energy transition	0	7	2	5	3	3.24
Collaboration between people with different professional backgrounds	1	5	7	1	3	3.00
Disruptive models	1	5	6	1	3	3.00
Limited crop diversity	0	7	8	0	2	2.82
Access to graduate students	4	4	5	2	2	3.65
Access to various types of waste for characterization	2	6	7	1	1	3.59

The third round of the study allowed the panel to share their agreement or disagreement about the remaining 42 items. The level of agreement identified was between 59% and 100%. In total, 30 critical issues were retained, and the remaining 12, which fell below 81%, were removed, as shown in table 2 below. An agreement of 100% was reached for seven critical issues. These top critical issues were the sales price of crops, profitability, labor costs, finding

markets (region specific), energy costs, cost of production, and cost of effectiveness. In addition, 14 critical issues achieved levels of 87% to 94% agreement, while 9 critical issues achieved levels of 81% to 82% agreement.

**Table 2.**

*The results of the third round of the Delphi study: level of consensus for critical issues facing the controlled environment agricultural industry (n = 42).*

Issue	Consensus (%)
Sales price of crops	100
Profitability	100
Labor costs	100
Finding markets (region specific)	100
Energy costs	100
Cost of production	100
Cost effectiveness	100
The initial capital investment	94
Market competition	94
Labor availability	94
Environmental control – HVAC	94
Energy management	94
Controlling Pests	94
High energy consumption	88
Production cost	87
Greenhouse environmental management	87
Food safety	87
Dealing with pathogens	87
Crop selection	87
Cost for maintenance	87
High input cost compared to traditional production	87
Access to funds to get started	82
The high cost of non-sustainable energy resources	81
More energy efficient equipment needed	81
Marketing	81
Lack of sound economic analysis	81
Identifying the right model	81
High infrastructure cost	81
Energy demands	81
Disease management	81
Marketability	75
Dependency on technology	75
Cost for improvement	75
Growing the right crops for market demand	75

Pathogen pressure	73
Quality of product	73
Import competition	71
Unit economics	69
Limited R&D capacities	65
Learning of the system	63
Lack of trained workers	63
Lack of relevant workforce development program	59

After completing the Delphi process, the remaining 30 items were analyzed using the constant comparative method (CCM). Eight overarching themes, each with one to ten issues, were identified. The emergent themes included (in alphabetical order) diseases and pests, energy, economic considerations, food Safety and quality, market dynamics, operation and infrastructure, startup capital, and workforce. The results of the CCM analysis are shown in Table 3 below.

**Table 3.**

*Constant comparative method thematic analysis results (n = 30).*

Issue	Number of Issues	Number of Issues with 90–100% Agreement
Disease and Pests	3	1
Controlling pests		
Dealing with pathogens		
Disease management		
Energy	4	1
Energy management		
High energy consumption		
More energy efficient equipment needed		
Energy demands		
Economic Considerations	10	4
Profitability		
Energy costs		
Cost of production		
Cost effectiveness		
Production cost		
Cost for maintenance		
High input cost compared to traditional production		
The high cost of non-sustainable energy resources		
Lack of sound economic analysis		
High infrastructure cost		
Food Safety and Quality	1	0

Food safety		
Market Dynamics	5	3
Sales price of crops		
Crop selection		
Finding markets (region specific)		
Market competition		
Marketing		
Operation and Infrastructure	3	1
Environmental control– HVAC		
Greenhouse environmental management		
Identifying the right model		
Startup Capital	2	1
The initial capital investment		
Access to funds to get started		
Workforce	2	2
Labor costs		
Labor availability		

#### 4. Discussion

The current study's results identified seven critical issues, with a 100% consensus. The seven critical issues were subsumed across three primary themes identified through the CCM: economic considerations, market dynamics, and workforce. Each core category represents several issues across the consensus spectrum and is interrelated. These data indicate that finding markets' regional specifics, sales price of crops, profitability, energy costs, labor costs, and cost of production significantly impact the controlled environment agricultural industry.

##### 4.1. Limitations

Even though the study results are intended to provide insights regarding the critical issues facing the controlled environment agricultural industry, several limitations should be acknowledged. First of all, the Delphi study's results are restricted to the views and opinions of the expert panel members. Although the panel was compiled with recognized industry leaders, there may still be an insufficient understanding of potential problems. Furthermore, respondents may interpret items generated throughout the process differently, making it impossible to ensure

that concepts are defined consistently. Despite these limitations, the study's results are further analyzed, and associated implications and recommendations are provided.

#### *4.2. Study Implications for Research and Practice*

The research results provide a unique perspective in guiding policy and initiatives in the controlled environment agricultural industry. The eight primary themes from analyzing the data presented a working framework, additional conclusions, implications, and recommendations that will help shape the CEA industry. Starting with the disease and pests theme, the emerging items were anticipated and unanticipated. With the argument that there is less pesticide usage in CEA systems because they produce food indoors, which is separated from the environment (Despommier, 2013), one would have thought that they are free from pests and diseases. However, there are still concerns about whether these systems can remain pest-free (Cowan et al., 2022). Because these systems use recirculation of nutrient solutions, the possibility of human pathogens contaminating the solutions and spreading within the system is high (Gómez et al., 2019). Based on these results, a recommendation would be to establish physical boundaries to prevent pathogens while using technology to monitor and detect pests and diseases and prevent their spread (Lauguico et al., 2019; Khan et al., 2021)

Several energy theme items were anticipated and well-established in the literature. For example, energy consumption was identified as the most challenging factor in CEA by several studies, mainly because of artificial lighting (Coon et al., 2024; Vatistas et al., 2022). According to Vatistas et al. (2022), energy consumed in greenhouse systems for heating and cooling is between 65-85% of the total energy required compared to the energy consumption of mechanical equipment, automation, and microclimate control systems, which are exceedingly small. However, in the plant factory artificial lighting systems, energy consumption accounts for 77-

93% of the energy requirement (Torres Pineda et al., 2020). A recommendation would be to use renewable energy as the systems' primary source of energy supply (de Carbonnel et al., 2022). Coon et al. (2024) identify local outdoor climate, technology choices and design, and electricity sources such as the power grid as the three factors that significantly affect the energy demand of CEA systems. They suggest the system's infrastructure, materials, components, and climate management techniques can affect energy demand. The recommendation is to select building materials suitable for the CEA systems' location. Additionally, a system design advanced in light modules and alternate energy systems that prevent the carbon cost of current systems should be encouraged (Dsouza, 2023) to reduce the energy demand.

The economic considerations theme was identified with many anticipated and unanticipated items based on previous themes within the literature. For instance, controlled environment agriculture is considered economically unviable due to its high startup and operational costs (Glaros, 2022). Based on the study's results, a recommendation would be to examine the possibility of reducing operating costs for profitability to promote the development of CEA systems (Engler & Krarti, 2021). To achieve this, growers can take advantage of the well-documented energy-saving measures to reduce the operating costs of CEA systems to facilitate a cost-effective business model (Iddio et al., 2020). It is reported that electrical costs can be reduced by 75.6% using red and blue LED lighting (Tong & Shimamura, 2013; Engler & Krarti, 2021), while reducing cost for maintenance by preventing infrastructure corrosion can minimize energy demand, yielding sufficient return on investment (Benke & Tomkins, 2017). Integrating renewable energy systems into CEA facilities, such as PV arrays and fuel cells, has proven cost-effective (Cowan et al., 2022). The Organic Photovoltaic Panels with 49% coverage

were also identified to meet the energy demands of off-grid CEA systems (Cowan et al., 2022). Applying these measures can help improve the productivity of CEA systems.

In the food safety and quality theme, one unanticipated item was identified. The result of the study shows that even though CEA products are perceived to have fewer potential food safety issues compared to conventional food production due to the controlled environmental conditions in CEA (Gómez et al., 2019), there are still concerns that need to be addressed. Studies show that pathogens can be introduced through human contact, water, and substrates into production systems (Olaimat & Holley, 2012; Shaw et al., 2016). Additionally, microorganisms, chemicals, and external contaminants within an urban food production system can pose food safety threats (Gómez et al., 2019). A recommendation would be to ensure proper training of the farm workers to uphold personal hygiene, sanitize the facilities, tools, and equipment, and enforce strict visitor policies to minimize or reduce the risks (Gómez et al., 2019).

Regarding the theme of market dynamics, some anticipated and unanticipated items were identified. For example, CEA systems mainly rely on leafy vegetables, which limits the range of crops suitable for this business—making it difficult for growers to select the type of crop and price that meets the diverse needs of the larger population—thus focusing on the small population of society that could afford the expensive leafy produce due to the high energy cost of production (Cox, 2016). To this end, a recommendation would be to breed and modify fruit and vegetable crops that are more suitable for indoor cultivation to improve the diversity of CEA food production (Kwon et al., 2020). Even though the study reflects previous studies that suggest that there are significant obstacles related to the marketing of CEA produce (Duston, 2017), understanding the market demand and the population of society that drives the market will be very beneficial to growers in determining the size of the competition, what to grow, and how

they can market their produce. As reported by Coyle and Ellison, consumers' positive attitude toward CEA produce is because of its potential to be environmentally friendly, reduce the price of food, and improve the quality of life (Coyle & Ellison, 2017). Therefore, a recommendation would be to improve CEA systems to make them more sustainable. Additionally, policymakers can provide some incentives to help reduce their operating costs and encourage them to reduce the price of products.

The operation and infrastructure themes anticipated items that were distinct from each other. For example, environmental control—HVAC items, critical factors in the operational cost of CEA systems—and greenhouse environmental management were anticipated. Additionally, identifying the right model based on the location when establishing CEA systems was anticipated. Based on these results, a recommendation would be to advance and refine the engineering processes utilized in CEA systems (Avgoustaki & Xydis, 2020) to optimize plant growth and production. From greenhouse environmental management, it is noted that large quantities of plant waste material from CEA systems can be overwhelming when the plan is to recycle them, which then end up in landfill (Castillo-Díaz et al., 2021), therefore, adopting an integrated system approach to reduce waste in CEA systems to ensure the proper environmental conditions can contribute to helping the system to be more sustainable (Cowan et al., 2022).

As related to the theme of startup capital, the items that were found were anticipated. For example, the high initial capital investment due to the system's infrastructural need and the lack of access to funding to support growers in starting their CEA system are well documented in the literature. To address these issues, a recommendation would be to repurpose an abandoned structure and warehouse into CEA systems to reduce the startup cost. Additionally, the local government can consider supporting CEA projects through funding or policy mechanisms

(Goodman & Minner, 2019), such as reducing taxes on CEA equipment and materials as well as providing incentives to help offset some of the operating costs. Alternatively, growers in CEA can partner with schools and donors interested in education and research to get the needed funding from which both partners could mutually benefit (Benke & Tomkins, 2017).

Lastly, the workforce theme had items that were anticipated. For example, the high-tech nature of CEA production requires highly technical and skilled workers, which is usually challenging for industry growers to find farm workers for employment opportunities (Muller et al., 2017; Carolan, 2023). According to Artemis (2020), labor cost was reported as the second largest contributor to CEA operations costs. For these notable concerns, a recommendation would be to integrate an educational component into the CEA business, where growers provide job training and skill development for individuals who want to work with them (Goodman & Minner, 2019). Growers could also reduce their labor costs through volunteer work from communities or schools that use their systems to help educate the students about the food system (Reisman, 2012). Educational institutions should have more opportunities and study programs to help educate the youth with the skills required to work in the CEA industry.

## **5. Conclusions**

The challenges associated with controlled environment agriculture have made it difficult for growers to adopt the CEA system even though the current conventional farming practice is unsustainable and unable to produce enough to meet the growing population. The current study provides insight into the critical issues that have made CEA's smooth scalability a challenge and the possible recommendations to address such challenges. The eight themes identified in the study serve as the framework for categorizing and addressing the critical issues facing the controlled environment agriculture industry. The results also provide a benchmark and

foundation for analyzing the critical issues facing the controlled environment agriculture industry. Future studies derived from the study's outcome will be used as case studies to explore critical issues further.

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## CHAPTER 4

# DEMOGRAPHIC CLASSIFICATION OF CONSUMERS' PERCEPTION OF CEA CRITICAL ISSUES<sup>2</sup>

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<sup>2</sup> Idun, A., Lamm, K. W., Holt, J., Lamm, A.J., & Park, M. To be submitted to *Horticulturae*.

## **Abstract**

Vertical farming, an emerging agricultural practice among controlled environment agriculture (CEA) systems, has gained considerable attention for its potential to revolutionize food production in urban environments sustainably. Consequently, policymakers and stakeholders in CEA need to develop strategies to support the industry, which involves gaining insight into consumers' views on CEA food production. However, while many studies cover controlled environment agriculture (CEA) and demographic characteristics, none address how demographics affect consumers' perceived importance of CEA issues. The main objective of this study is to describe the U.S. consumers' perceptions of CEA critical issues and to determine whether statistically significant differences exist between perceptions of CEA critical issues based on audience segmentation. Data was collected through the Qualtrics survey instrument and analyzed using the Statistical Package for Social Sciences (SPSS) version 29. The study indicated that differences in gender, region, and education level do not affect consumers' perceptions of the importance of CEA issues. However, age differences were identified to have a statistically significant influence on perceptions of all the CEA critical issues, with older respondents rating the issues as more important than younger respondents. Given that older consumers perceive CEA issues as more critical, outreach efforts should be tailored to address their concerns, while younger consumers should be targeted with content that increases their interest and awareness of CEA technology. Policymakers should also work with CEA industry stakeholders to develop regulations and incentives that address consumer concerns. Producers should also provide the opportunity for consumers to learn about CEA production systems.

## 1. Introduction

Even though access to sufficient and safe food is a priority for humanity (Agboklou et al., 2024), in 2021, it was estimated that 691-783 million people were food insecure globally (FAO, 2023). This suggests that achieving the 2030 Agenda of zero hunger will be far from being a reality in all regions of the world (Agboklou et al., 2024) if struggling traditional agricultural practices are not replaced with an innovative solution capable of keeping pace with the increasing demand for fresh produce to feed the growing urban population (Akintuyi, 2024). However, vertical farming, an emerging agricultural practice among the controlled environment agriculture (CEA) systems, has gained considerable attention for its potential to revolutionize food production in urban environments sustainably (Akintuyi, 2024). Consequently, policymakers and stakeholders in CEA need to develop strategies to support the industry, which involves gaining insight into consumers' views on CEA food production.

### *1.1. Controlled Environment Agriculture (CEA)*

Controlled environment agriculture (CEA), a term commonly used to group several alternative farming practices such as a greenhouse, high tunnel, and plant factory, or vertical farming “refers to methods that cultivate crops within a controlled environment, meaning that variables such as sunlight, water, airflow, and nutrients are all controlled by the grower to establish optimal growing conditions for the crops” (Hjorth & Dexner, 2023, p. 2). Over the years, the global CEA market has grown, and it is projected to rise even further (Nwanojuo et al., 2025) to dominate the fresh food production market. According to Lighting (2024), the CEA market was forecasted to rise from \$2.23 billion in 2018 to \$12.77 billion by 2026. However, the global market valuation of CEA was \$17.8 Billion in 2022, and it is expected to reach \$32.5

Billion by 2028 (Hjorth & Dexner, 2023). This growth results from the increase in the number of new CEA agribusinesses worldwide (Nwanojuo et al., 2025).

### *1.2.CEA Market Growth*

Several factors are driving the CEA market. However, its perceived sustainability is the primary driver of consumer acceptance (Gan et al., 2022). Consumer awareness about what they eat and their preference for top-quality, fresh, and nutritious products all year round (Lensing, 2018) is also a factor for CEA market growth. Ethics and environmental issues were identified in consumer research to contribute to the increased acceptance of CEA-grown products (Grunert et al., 2008; Grebitus et al., 2013; Feldmann & Hamm, 2015). The potential of CEA to improve food supply and security was identified as an important factor in the drive to advance CEA production (Avgoustaki & Xydis, 2020; Kalantari et al., 2018; O’Sullivan et al., 2020). In the Middle East, where fresh water is a scarce commodity, CEA is considered the best approach to food production (Hjorth & Dexner, 2023). Furthermore, CEA systems have become the best alternative to conventional farming in places with a shortage of arable land or high population density, such as urban cities, Singapore, or Japan (Hjorth & Dexner, 2023). Finally, another driver of the CEA market growth is the increasing climate and weather instability brought about by climate variability (Hjorth & Dexner, 2023).

### *1.3.Challenges of the CEA Market*

Although both consumers and growers are motivated to accept CEA production, several factors challenge its scalability, affecting the CEA market's growth. For instance, high investment and high levels of technical knowledge are required to establish and operate CEA systems (Specht et al., 2019; Kalantari & Akhyani, 2021). The high energy requirements and the cost associated with CEA production limit its ability to reduce global warming (Broad et al.,

2022). Currently, CEA operations typically target high-end consumers who pay premium prices for quality produce (Gan et al., 2022), leading to doubts about its role in global food security. CEA food production lacks variety, especially in vertical farming; leafy greens and herbs are the most economically feasible to grow (Broad et al., 2022), resulting in low interest in CEA production by growers (Specht et al., 2019). The lack of information about the nutritional content of CEA-grown produce has led to the misconception that its products are less healthy (Gibson et al., 2023). Some consumers have questions regarding CEA-grown products' safety and potential contamination risks (Huang, 2019; Yano et al., 2021). The uncertainties about CEA production contribute to the distrust and concerns among consumers (Gibson et al., 2023).

#### *1.4. Public Perception of CEA and Demographic Characteristics*

Public understanding of CEA systems and concepts can affect the growth and development of the CEA market in various ways (Hjorth & Dexner, 2023). Consumers' access to information on CEA production and their understanding of the benefits may vary based on demographic factors such as geographic location or economic status. It is important to note that tailored communication based on consumer perception will play a significant role in the CEA industry moving forward (Ronteltap et al., 2007). However, although several studies seek to understand consumers' perception of CEA, little information is available on the demographic differences in how consumers evaluate CEA systems and production (Broad et al., 2022). To fill the gap, this study tries to study the demographic classification of consumers in relation to the CEA critical issues, which serves as a barrier to the scalability of the CEA industry.

#### *1.5. Theoretical Framework*

Audience segmentation offers a robust theoretical framework for this study. This technique is advantageous when examining a large and diverse population because it can assist in

establishing subgroups with shared characteristics relevant to behavior that inform the design and delivery of a targeted media campaign (Warner et al., 2022). Identifying subgroups and their associated characteristics provides the basis for educators and communicators to carefully and strategically understand how to craft target messages for their audiences (Orton et al., 2024). It has been identified that in audience segmentation, individuals are classified according to their behavioral, psychological, geographical, socioeconomic, or demographic attributes (Schmidt et al., 2024; D. Newton et al., 2013), allowing for analysis based on the between-group differences rather than the within-group differences (Hine et al., 2014).

Several studies have used audience segmentation to understand consumers' perspectives on pressing issues. According to Degeneffe et al. (2009), the segmentation framework assists decision-makers in better understanding consumer needs and concerns. This knowledge helps craft messages that address the individual's information needs and choose the appropriate media channels to communicate them. Audience characteristics, such as demographics, have been identified to contribute to meaningful subgroups that guide extension program design (Warner et al., 2022a). Huang et al. (2016), in their study “Informing Extension Program Development through Audience Segmentation: Targeting High Water Users,” identified that high-water users shared demographic characteristics with previous studies conducted by Monaghan et al. (2013), which found that the high-water users were older and had higher incomes and education levels than the public.

### *1.6. Controlled Environment Agriculture and Age*

According to Shao et al. (2022), age differences significantly affect intentions to use vertical farming. Their study identified young adults between 31 and 40 with positive intentions toward using controlled-environment agriculture systems to produce food. As Broad et al. (2022)

noted from the 2020 Global CEA Census, these young individuals interested in food, technology, and entrepreneurship who have rushed into the CEA industry may have little to no agricultural experience. However, since young people generally have innovative mindsets, they are naturally attracted to CEA farming systems (Eßmann, 2024), which allow them to explore agriculture technologies. Additionally, studies show that sustainability issues, now the concern of young people, are one of the principal drives for consumer acceptance of vertical farming among the youth (Perambalam et al., 2021).

### *1.7. Controlled Environment Agriculture and Gender*

Findings from a study conducted by Nishi (2017) identified that gender was a significant factor in influencing consumers' willingness to pay for locally grown vegetables produced from controlled environment agriculture. The findings also show that consumers' willingness to pay increased by 36% among females, which was higher than that of males. Several studies have found similar evidence that females are more likely to pay more for locally grown vegetables than their male counterparts (Yue et al., 2009; Boccaletti & Nardella, 2000). The recent increase in women's interest and involvement in CEA is due to the fact that it offers them the opportunity to contribute to food security and the household economy in a more convenient way (Griebel et al., 2022). This is because CEA production is environmentally friendly and does not require hard labor and intense physical work. However, although several studies support gender influence on accepting indoor farming, a study by Ezzeddine (2023) on respondents' gender self-identification indicated that all respondents, regardless of gender, preferred field-grown lettuce to indoor-grown lettuce.

### *1.8. Controlled Environment Agriculture and Educational Level*

Consumers' Education levels were found not to have a strong relationship with CEA acceptance levels (Zhou et al., 2022). An analysis of choices based on respondents' level of education indicated that those with a college degree preferred field-grown lettuce to indoor-grown lettuce, while respondents without a degree did not have a statistically significant preference between field- or indoor-grown lettuce (Ezzeddine, 2023). However, according to Eßmann (2024), the more consumers are educated on vertical farming and specific vertical farming product characteristics that influence their purchasing decisions towards accepting CEA-grown produce.

### *1.9. Controlled Environment Agriculture and Geography*

When planning to start indoor farming, the farm's location should be considered to maximize its benefits (Dinnie & MacLean, 2022). Studies have shown that geographic location is a significant factor in CEA's economic and environmental sustainability feasibility (Cowan et al., 2022). The climate of a hydroponic location can require a large amount of cooling in the climate control system, thus resulting in high energy consumption (Newman, 2015). Therefore, it will be unsustainable to establish a commercial hydroponic system in such a place (Barbosa et al., 2015). However, a greenhouse system in more moderate climate conditions close to the greenhouse set point temperature is noted to experience a lower energy demand (Griebel et al., 2022). This suggests that more rigorous studies of the energy footprint in different climate locations should be conducted to determine where the CEA farm should be built (Duston, 2017). There are also several benefits of situating a CEA farm at the end of the supply chain (Dinnie & MacLean, 2022). Apart from reducing greenhouse gas emissions from transporting food to

consumers, it also creates opportunities for consumers to participate in or witness how food is grown in CEA systems and offers them the opportunity to learn how to operate such systems.

#### *1.10. Controlled Environment Agriculture and Household Income*

Ares et al. (2021) found that higher-income people are generally more willing to pay for CEA-grown products. In a study by Carpio and Isengildina-Massa (2009) that analyzed the socio-demographic characteristics of consumers and their influences on willingness to pay for locally grown products, the results show that willingness to pay was positively correlated with consumers' income. However, Ezzeddine (2023) identified that, based on annual household income, all respondents preferred field-grown lettuce to indoor-grown lettuce. Again, household income was found to be insignificant in vertical farming usage among people of different annual household incomes (Shao et al., 2022). While many studies cover controlled environment agriculture (CEA) and demographic characteristics, none address how demographics affect consumers' perceived importance of CEA issues.

#### *1.11. Study Purpose*

The purpose of this study was to identify consumers' demographic characteristics as they relate to their insights regarding the perceived importance of CEA critical issues. The following research objectives will guide the study:

1. Describe U.S. consumer perceptions of CEA critical issues.
2. Determine whether statistically significant differences exist between perceptions of CEA critical issues based on audience segments.

## **2. Materials and Methods**

### *2.1. Research Design*

Using quantitative research design, we achieved our research objectives and purpose. The target audience for the study was adults living in the United States. Based on the literature, we have developed a sampling frame using nonprobability opt-in sampling methods (see Lamm & Lamm 2019). Institutional Review Board approval was obtained from the University of Georgia (IRB: STUDY00008659). A set of criteria was established for selecting respondents based on the demographic distributions provided by the U.S. Census. The data collected for the present study were part of a larger research project and are disclosed following literature recommendations for clarity (see Kirkman & Chen 2011).

### *2.2. Instrumentation and Data Collection*

The study was informed by a set of critical issues facing CEA production identified through a Delphi analysis. Concerning the CEA critical issue that the public considers to be major or minor, the participants were asked to respond to two items on a five-point semantic differential scale: 1 – A minor issue through 5 – A major issue, and 1 – Trivial through 5 – Critical, for each CEA critical issue (e.g., “Control management of disease and pests”). This scale was developed based on recommendations from the literature (see Asghar et al., 2020). An index score was calculated for each of the eight critical issues by summing the two items and dividing the result by two. Internal structure validity was established using Cronbach’s alpha. Results for the eight items are displayed in Table 1. Values were deemed acceptable based on established social science thresholds.

**Table 4.**  
*Cronbach's Alpha values (N = 776).*

<b>Critical Issue</b>	<b>Alpha</b>
Control and management of disease and pests	0.70
Energy use in production	0.72
Overall food safety and quality	0.69
Startup capital required	0.75
Workforce availability	0.73

Respondents were also asked to provide several demographic characteristics, including age, gender, educational level, and income. Data was collected in February and March 2025. A total of 776 usable responses were obtained.

### *2.3. Data Analysis*

The data were analyzed using the Statistical Package for Social Sciences (SPSS) version 29. The first step was to calculate frequencies for all demographic characteristics as well as descriptive statistics for the critical issue index variables. Next, differences between the demographic groups were analyzed using a one-way ANOVA (Keith, 2005). Statistically significant differences between groups were analyzed post hoc using Bonferroni tests. The effect sizes for each ANOVA analysis were presented as Partial Eta Squared values. We then interpreted the effect sizes according to the guidelines provided by Cohen (1988).

### **3. Results**

Descriptive statistics for perceptions of critical issues facing the CEA industry for each issue area are presented in Table 2.

**Table 5.***Descriptive Statistics Related to CEA Critical Issues (N = 776).*

<b>Critical Issue</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>SD</b>
Overall food safety and quality	1.00	5.00	4.19	0.90
Control and management of disease and pests	1.00	5.00	4.11	0.89
Startup capital required	1.00	5.00	4.00	0.91
Energy use in production	1.00	5.00	3.86	0.90
Workforce availability	1.00	5.00	3.72	0.92

Descriptive statistics for perceptions of critical issues facing the CEA industry for each demographic cluster are presented in Tables 3 through 10.

**Table 6.***Perceptions of Overall Food Safety and Quality (N = 776).*

<b>Characteristic</b>	<b>N</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>SD</b>	<b>F</b>	<b>p</b>	<b><math>\eta_p^2</math></b>
<b>Gender</b>						2.931	0.087	.004
Male	293	1.00	5.00	4.11	0.94			
Female	482	1.00	5.00	4.23	0.87			
<b>Age</b>						5.425**	0.005	.014
18 to 34	279	1.00	5.00	4.17	0.91			
35 to 54	365	1.00	5.00	4.27	0.83			
55 and Over	132	1.00	5.00	3.98	1.01			
<b>Education</b>						3.285	0.006	.021
Less than 12 <sup>th</sup> grade	20	1.00	5.00	4.20	1.11			
High school diploma/GED	173	1.00	5.00	4.01	0.98			
Some college - no degree	164	1.00	5.00	4.34	0.86			
2-year college degree	96	1.00	5.00	4.36	0.77			
4-year college degree	224	1.00	5.00	4.18	0.84			
Graduate or Professional degree	99	1.00	5.00	4.08	0.95			
<b>Region</b>						0.433	0.729	.002

Midwest	182	1.00	5.00	4.24	0.83
Northeast	146	1.00	5.00	4.20	0.88
South	298	1.00	5.00	4.17	0.94
West	150	1.00	5.00	4.14	0.92

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$  (Note: 1 = least important; 5 = most important)

**Table 7.**

*Perceptions of Control and Management of Disease and Pests (N = 776).*

Characteristic	N	Min	Max	Mean	SD	F	p	$\eta_p^2$
<b>Gender</b>						7.108**	.008	.009
Male	293	1.00	5.00	4.00	0.96			
Female	482	1.00	5.00	4.17	0.84			
<b>Age</b>						5.106**	0.006	.013
18 to 34	132	1.00	5.00	3.91	0.97			
35 to 54	279	1.00	5.00	4.09	0.90			
55 and Over	365	1.00	5.00	4.19	0.84			
<b>Education</b>						3.319**	0.006	.021
Less than 12 <sup>th</sup> grade	20	1.00	5.00	4.03	1.18			
High school diploma/GED	173	1.00	5.00	3.99	0.99			
Some college - no degree	164	2.00	5.00	4.31	0.75			
2-year college degree	96	1.00	5.00	4.23	0.76			
4-year college degree	224	1.50	5.00	4.06	0.85			
Graduate or Professional degree	99	1.00	5.00	3.98	0.97			
<b>Region</b>						0.781	0.505	.003
Midwest	182	1.50	5.00	4.18	0.78			
Northeast	146	1.00	5.00	4.14	0.85			
South	298	1.00	5.00	4.06	0.97			
West	150	1.00	5.00	4.08	0.87			

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$  (Note: 1 = least important; 5 = most important)

**Table 8.***Perceptions of Startup Capital Required (n = 776).*

<b>Characteristic</b>	<b>N</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>SD</b>	<b>F</b>	<b>p</b>	<b><math>\eta_p^2</math></b>
<b>Gender</b>						1.408	0.236	.002
Male	293	1.00	5.00	4.05	0.88			
Female	482	1.00	5.00	3.97	0.92			
<b>Age</b>						26.329***	0.000	.064
18 to 34	132	1.00	5.00	3.59	0.96			
35 to 54	279	1.00	5.00	3.91	0.94			
55 and Over	365	1.00	5.00	4.22	0.81			
<b>Education</b>						3.651**	0.003	.023
Less than 12 <sup>th</sup> grade	20	1.00	5.00	3.95	1.21			
High school diploma/GED	173	1.00	5.00	3.76	1.01			
Some college - no degree	164	2.00	5.00	4.14	0.86			
2-year college degree	96	1.00	5.00	4.11	0.88			
4-year college degree	224	1.00	5.00	4.00	0.84			
Graduate or Professional degree	99	1.00	5.00	4.08	0.86			
<b>Region</b>						0.407	0.748	.002
Midwest	182	1.00	5.00	4.03	0.87			
Northeast	146	1.00	5.00	3.99	0.88			
South	298	1.00	5.00	3.96	0.96			
West	150	1.00	5.00	4.05	0.88			

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$  (Note: 1 = least important; 5 = most important)

**Table 9.***Perceptions of Energy Use in Production (n = 776).*

<b>Characteristic</b>	<b>N</b>	<b>Min</b>	<b>Max</b>	<b>Mean</b>	<b>SD</b>	<b>F</b>	<b>p</b>	<b><math>\eta_p^2</math></b>
<b>Gender</b>						0.006	0.937	.000

Male	293	1.00	5.00	3.86	0.94			
Female	482	1.00	5.00	3.85	0.87			
<b>Age</b>						5.627**	0.004	.014
18 to 34	132	1.00	5.00	3.63	0.91			
35 to 54	279	1.00	5.00	3.88	0.91			
55 and Over	365	1.00	5.00	3.93	0.88			
<b>Education</b>						1.719	0.128	.011
Less than 12 <sup>th</sup> grade	20	3.00	5.00	3.98	0.80			
High school diploma/GED	173	1.00	5.00	3.71	1.02			
Some college - no degree	164	1.00	5.00	3.96	0.89			
2-year college degree	96	1.00	5.00	3.87	0.87			
4-year college degree	224	1.50	5.00	3.91	0.79			
Graduate or Professional degree	99	1.00	5.00	3.81	0.95			
<b>Region</b>						1.675	0.171	.006
Midwest	182	1.00	5.00	3.90	0.81			
Northeast	146	1.00	5.00	3.83	0.92			
South	298	1.00	5.00	3.79	0.94			
West	150	1.00	5.00	3.98	0.89			

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$  (Note: 1 = least important; 5 = most important)

**Table 10.**

*Perceptions of Workforce Availability (N = 776).*

Characteristic	N	Min	Max	Mean	SD	F	p	$\eta_p^2$
<b>Gender</b>						1.329	0.249	.002
Male	293	1.00	5.00	3.68	0.93			
Female	482	1.00	5.00	3.75	0.91			
<b>Age</b>						4.061*	0.018	.010
18 to 34	132	1.00	5.00	3.52	1.03			

35 to 54	279	1.00	5.00	3.76	0.91			
55 and Over	365	1.00	5.00	3.77	0.87			
<b>Education</b>						1.136	0.340	.007
Less than 12 <sup>th</sup> grade	20	1.00	5.00	3.58	1.20			
High school diploma/GED	173	1.00	5.00	3.66	1.03			
Some college - no degree	164	1.00	5.00	3.83	0.90			
2-year college degree	96	1.00	5.00	3.83	0.86			
4-year college degree	224	1.50	5.00	3.67	0.83			
Graduate or Professional degree	99	1.00	5.00	3.71	0.93			
<b>Region</b>						1.382	0.247	.005
Midwest	182	1.00	5.00	3.84	0.85			
Northeast	146	1.00	5.00	3.71	0.93			
South	298	1.00	5.00	3.67	0.94			
West	150	1.00	5.00	3.69	0.93			

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Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$  (Note: 1 = least important; 5 = most important)

### 3.1. CEA Issue Perceptions and Gender

The perceptions of overall food safety and quality ( $F = 2.931$ ,  $p = 0.087$ ), perceptions of startup capital required ( $F = 1.408$ ,  $p = 0.236$ ), perceptions of energy use in production ( $F = 0.006$ ,  $p = 0.937$ ), and perceptions of workforce availability ( $F = 1.329$ ,  $p = 0.249$ ), were all found to have no statistically significant relationship with gender. The observed effect size for these critical issues was considered negligible (Cohen, 1988). However, gender differences were statistically significant with the perceptions of control and management of disease and pests ( $F = 7.108$ ,  $p < .01$ ).

### *3.2. CEA Issue Perceptions and Age*

The perceptions of overall food safety and quality ( $F = 5.425, p < 0.01$ ), perceptions of control and management of disease and pests ( $F = 5.106, p < .01$ ), perceptions of startup capital required ( $F = 26.329, p < 0.001$ ), perceptions of energy use in production ( $F = 5.627, p = 0.004$ ), and perceptions of workforce availability ( $F = 4.061, p < .05$ ) were all found to be statistically significant with differences in age with older respondents perceiving these CEA issues as more important than the younger respondents.

### *3.3. CEA Issue Perceptions and Educational Attainment*

The perceptions of overall food safety and quality ( $F = 3.285, p = 0.006$ ), perceptions of energy use in production ( $F = 1.719, p = 0.128$ ), perceptions of control and management of disease and pests ( $F = 3.319, p < .01$ ) and perceptions of workforce availability ( $F = 1.136, p = 0.340$ ) all showed no statistically significant relationship with educational attainment. The observed effect size was considered negligible for these CEA issues (Cohen, 1988). On the other hand, the perceptions of startup capital required ( $F = 3.651, p = 0.003$ ) were found to have a statistically significant relationship with differences in educational level. However, the effect size for these CEA issues remained small, which was considered negligible (Cohen, 1988).

### *3.4. CEA Issue Perceptions and Geographic Region*

The perceptions of overall food safety and quality ( $F = 0.433, p = 0.729$ ), perceptions of control and management of disease and pests in CEA ( $F = 0.781, p > .05$ ), perceptions of startup capital required ( $F = 0.407, p = 0.748$ ), perceptions of energy use in production ( $F = 1.675, p = 0.171$ ), and perceptions of workforce availability ( $F = 1.382, p = 0.247$ ) were all found to have no statistically significant difference by region. The observed effect size was considered negligible for these CEA issues (Cohen, 1988).

#### 4. Discussion

Even though studies have shown that public understanding and awareness of CEA systems and concepts can affect the growth and development of the CEA industry (Hjorth & Dexner, 2023), there is a lack of information about CEA production, making consumers distrust CEA-grown produce (Gibson et al., 2023). Therefore, this study aimed to identify consumers' demographic characteristics related to their insights regarding the perceived importance of CEA critical issues.

The results of this study suggest that gender differences were only statistically significant in the control and management of disease and pests but did not play a statistically significant role in shaping perceptions of the rest of the critical issues related to controlled environment agriculture (CEA). This suggests that any observed differences in perception between men and women are not strong or consistent enough to be attributed to gender alone. Instead, other variables—such as experience, access to resources, or professional background—may be more influential in shaping perceptions of CEA. This means that policies or interventions addressing differences in perception should focus on these other factors rather than assuming gender-based distinctions. These results align with a previous study by Brush et al. (2002), arguing that variations in startup capital perceptions are more influenced by industry type, geographic location, and prior business exposure than gender alone.

The findings of this study highlight significant age-related differences in perceptions of various aspects of Controlled Environment Agriculture (CEA). This indicates that age contributes to shaping perceptions of CEA feasibility. However, it is interesting to note that older respondents were identified to rate the CEA issues as more important than younger respondents. This implies that tailored outreach and education programs may be needed to address the varying

concerns of different age groups, ensuring that younger individuals are adequately informed about CEA-related issues while addressing older individuals' concerns relating to CEA feasibility.

The results also indicated that apart from the perceptions of startup capital required that education was statistically significant, educational attainment did not significantly influence perceptions of the rest of CEA critical issues. This suggests that individuals with different educational backgrounds may have slightly varying perspectives on CEA's financial and biological challenges. One possible explanation is that individuals with higher educational attainment may have greater exposure to financial literacy and risk assessment, which could influence their perceptions. Conversely, those with less formal education may rely more on experiential knowledge or practical insights, leading to differing viewpoints on these specific issues. However, effectively communicating and addressing these concerns across diverse educational backgrounds will be crucial for fostering a more inclusive and informed CEA industry.

The results indicated that regional differences did not significantly influence consumers' perceptions of the CEA issues under study. The findings showed relatively uniform perceptions of CEA issues across different regions. However, the West was identified to have a slightly higher rating than other regions regarding operational and infrastructure requirements. A nationwide marketing campaign emphasizing CEA's benefits can be effective given that perceptions are relatively uniform. A noteworthy limitation associated with the study findings is that the consumers were only the focus; therefore, the response may not reflect the thoughts of producers in different regions about CEA. Future research should compare these findings with producer perspectives to identify alignment or gaps in understanding and expectations. Another

limitation is that all the effect sizes for the critical issues were observed to be small. Therefore, interpretation of the findings should be done with caution. A recommendation for future research is to examine further whether more salient audience segments may have more significant associated effects on perceptions of critical issues in CEA.

Overall, the present research suggests practice recommendations. First, given that older consumers perceive CEA issues as more critical, outreach efforts should be tailored to address their concerns, while younger consumers should be targeted with content that increases their interest and awareness of CEA technology. Additionally, policymakers should work with CEA industry stakeholders to develop regulations and incentives that address consumer concerns. This includes food safety certification programs, financial support for infrastructure, and initiatives to promote public trust in CEA produce.

Additionally, recommendations for future research explore whether direct exposure to CEA facilities (e.g., farm visits, interactive training) influences consumer perceptions differently compared to theoretical knowledge from educational programs. A further recommendation would be that although consumer perceptions were relatively uniform across regions, it would be beneficial to study whether regional infrastructure, climate conditions, or policy environments influence producers' willingness to adopt CEA practices. Future research should examine whether perceptions of CEA issues change as individuals gain more experience. This could help determine whether younger individuals' lower prioritization of specific CEA issues is due to inexperience or evolving industry trends. Future studies could analyze how media representation and marketing campaigns impact consumer trust and awareness of CEA. Understanding the role of digital content and social media in shaping perceptions would help design effective outreach strategies.

Lastly, given that consumer perceptions may differ from those of producers, industry stakeholders should establish collaborative dialogues between consumers and producers. This can be done through forums, focus groups, or participatory research initiatives to align expectations and practical realities in CEA.

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## CHAPTER 5

# THEORY OF PLANNED BEHAVIOR: WILLINGNESS TO CONSUME CEA-GROWN PRODUCTS<sup>3</sup>

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<sup>3</sup> Idun, A., Lamm, K. W., Holt, J., Lamm, A.J., & Park, M. To be submitted to *Horticulturae*.

## **Abstract**

The CEA industry is growing fast. Meanwhile, most producers are unwilling to transition from conventional crop production methods to controlled environment agriculture (CEA) systems. This is because producers are not well convinced of the industry's profitability. However, consumers' attitudes toward CEA agriculture must be considered when determining the industry's feasibility. In response, there has been a large body of work on consumer preferences and willingness to pay for CEA-grown produce. However, there is a noteworthy gap in the literature, specifically on consumers willing to consume CEA-grown produce. This study mainly investigates consumers' willingness to consume CEA-grown produce using the Theory of Planned Behavior (TPB) as a guide. Data was collected through the Qualtrics survey instrument and analyzed using the Statistical Package for Social Sciences (SPSS) version 29. The study identified that there is a generally positive attitude toward CEA-grown produce. It was shown that even though all three constructs of TPB are statistically significant in influencing consumers' intention to consume CEA-grown products, the subject norm ranks the highest. The findings suggest that to create awareness about CEA-grown produce and encourage consumer acceptance, producers and stakeholders should organize community events, farm tours, or cooking demonstrations featuring CEA-grown produce to foster a sense of community and normalize consumption among older consumers while using social media campaigns to educate younger consumers about the benefits of CEA, including sustainability, reduced pesticide use, and year-round availability.

## 1. Introduction

The CEA industry is fast growing. Meanwhile, most producers are unwilling to transition from conventional crop production methods to controlled environment agriculture (CEA) systems. However, producers can only succeed in the complex nature of consumer demand in the global marketplace if they can quickly identify changing consumer demand patterns and adopt agricultural practices reflecting consumers' needs (Nishi, 2017), and while current studies suggest that producers are more likely to adopt a new method of production based on consumer preferences, emerging food trends have identified that consumers are driven by factors such as taste, nutrition, availability, seasonality, distance traveled from farm to table, pesticide use, and environmentally sustainable farm practices such as CEA production (Nishi, 2017). This suggests that in determining the feasibility of the CEA industry, consumers' attitudes toward CEA agriculture must be considered (Charlebois et al., 2021).

According to Ares et al. (2021), there is evidence that consumers overall have a positive perception of the CEA industry. As noted by Dohlman et al. (2024), this positive attitude by consumers is driven by the perceived sustainability that the CEA industry seeks to offer. “Another driver of the CEA market’s growth is the increasing climate and weather instability caused by climate change” (Hjorth & Dexner, 2023, p. 35), which affects productivity and the year-round availability of fresh produce that, unlike field production, CEA systems have an advantage of due to its ability to protect crops from direct extreme weather conditions. These and many other benefits of CEA systems, such as offering consumers fresh produce with quality taste and flavor and possibly better nutritional content compared to crops grown on soil (Nie & Zepeda, 2011; Coyle & Ellison, 2017; Broad et al., 2022), it is well established in the literature that CEA systems can boost the production of locally-grown vegetables and fruits (Nishi, 2017),

offering employment opportunities for urban and cities settlers and boosting the local economy (Brown, 2003; Loureiro & Hine, 2002) and helping to achieve sustainable development goal 1, 2, 3, 6 and 8.

Over the years, advocates and scholars of the CEA industry have written and spoken about the potential benefits of CEA systems and the possibilities of replacing open-field crop production. However, some concerns need to be addressed, such as consumers' skepticism about the acclaimed advantages of CEA due to a lack of knowledge of CEA production (Pfeiffer et al., 2021). It is, therefore, important for CEA producers and stakeholders to bridge the knowledge gap among the diverse forms of CEA systems to improve consumers' minimal awareness (Broad et al., 2022) because the CEA market success depends on the industry's ability to identify local food consumers and specifically tailor communication and education materials to them, making the case that CEA-grown produce is truly local, sustainable, and natural (Broad et al., 2022).

As noted by Hjorth and Dexner (2023), public awareness and acceptance of CEA systems are important factors to consider when it comes to the market growth and development of the CEA industry. According to them, the “low awareness among consumers about the benefits of CEA systems compared to conventional farming practices might limit the actors' customers' ability to sell the CEA-cultivated crops to potential consumers” (Hjorth & Dexner, 2023, p.30). Studies also show that the CEA industry needs to deliver on its promises of providing high-quality produce that competes with other existing options in terms of price, freshness, taste as well as sustainable means of production (Broad et al., 2022) to gain the trust of consumers and possibly leads to their acceptance of CEA-grown produce.

Given the importance of consumers' role in determining the economic viability of the CEA industry, there have been several studies to understand the perceptions of consumers on

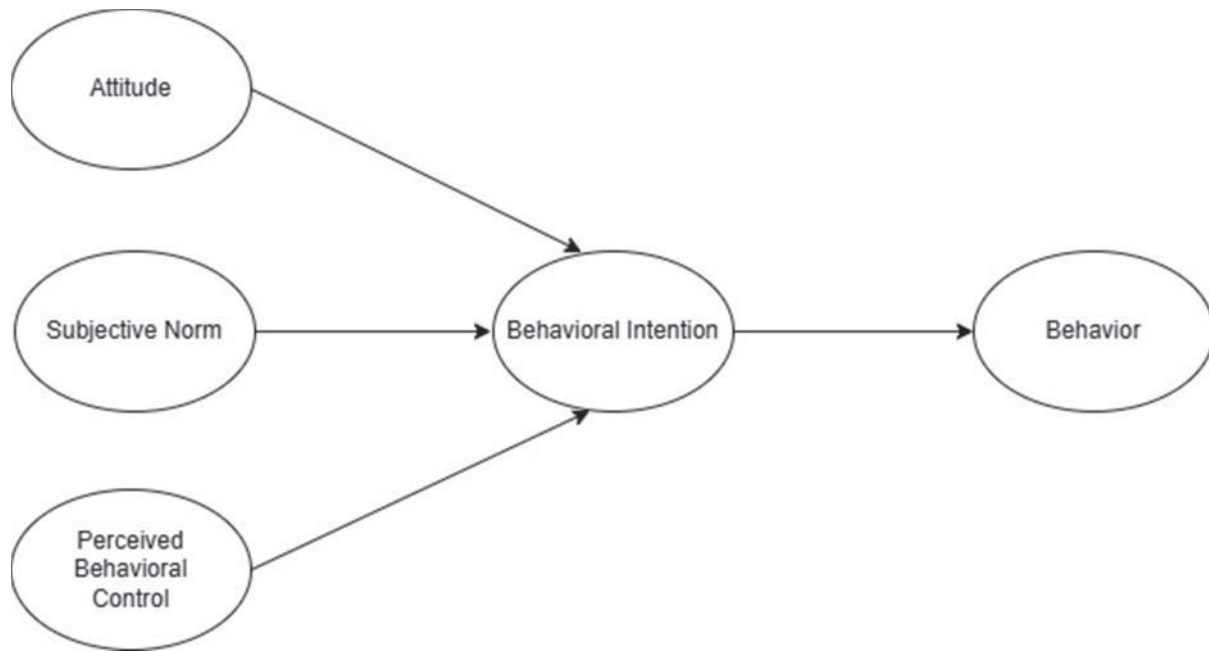
CEA-grown produce and systems (Broad et al., 2022). A typical example is a study conducted by Ilaslan et al. (2002) to examine the economic viability of CEA systems in the production of lettuce. The study found that the most important factors consumers consider when purchasing lettuce are price, freshness, appearance, and convenience in finding it whenever they need it. Other studies on the consumers' willingness to pay for CEA-grown produce reported that the perceived safety and expected quality, as well as providing public education on CEA-grown produce and systems (Coyle & Ellison, 2017; Narine et al., 2014; Nishi, 2017) contribute to consumers acceptance and viability of CEA industry. Although this suggests a large body of work on consumer preferences and willingness to pay for CEA-grown produce, there is a noteworthy gap in the literature, specifically on consumers willing to consume CEA-grown produce. This study, therefore, seeks to investigate consumers' willingness to consume CEA-grown produce using the Theory of Planned Behavior (TPB) as a guide.

### *1.1. Theoretical Framework and Hypothesis*

The theory of planned behavior (TPB) proposed by Ajzen in 1985 explains how individuals' attitudes, behavioral control, and subjective norms influence behavioral intention, where the intention is considered a mediating predictor of behavior. Ajzen (1991) asserted that it is essential to consider the influence of relevant background variables, including personal characteristics and experience, to improve the accuracy of predicting human intentions. According to Al-Swidi et al. (2014), TPB focuses on an individual's intention to perform a behavior. Thus, when the key constructs of TPB support a particular behavior, they encourage the intention to perform it. This theory has been widely implemented in various disciplines to explain an individual's motivation and associated behaviors. Baby and Joseph (2024) applied the TPB to understand travelers' intention to purchase local foods in tourist destinations. They

identified that along with the traveler's attitude, the traveler's subjective norm was also a significant factor in influencing their purchase intentions. Another study by Shao et al. (2022) investigated the public acceptance and willingness to use vertical farming in planting by selecting behavioral intentions to assess public willingness to use the innovation. The key finding was that public attitudes and behavioral intentions toward micro-vertical farming are better than neutral but slightly less favorable.

In predicting consumer intention and behavior, TPB has been successfully applied to several studies in consumer research (Mathieson, 1991; Yadav & Pathak, 2016). As Canova et al. (2020) noted, many studies within the food consumption literature have assumed TPB as their theoretical reference to investigate the psychological factors that explain consumers' intentions and behaviors. Furthermore, Qi and Ploeger (2019) found that notable studies successfully used TPB to predict consumers' food choices. A typical example is a study by Dunn et al. (2011), which identified that TPB could predict 50% of the intention variance of fast-food consumption. Additionally, a meta-analysis covering 23 independent studies conducted by Scalco et al. (2017) suggests that TPB is an adequate theoretical framework for predicting the intention to purchase and consume organic food. It is important to note that the consumer behavior, as predicted by the TPB, is determined by the stated behavioral intention, which is influenced by the three constructs of TPB: attitude, which is the positive or negative evaluation of the behavioral consequences; subjective norm which is the perceived social pressure to engage in the behavior, and perceived behavioral control (PBC) which is related to the individual's perception of his/her ability to perform the behavior (Carfora et al., 2019).



*Fig. 3. The Theory of Planned Behavior*

According to Saxena and Vij (2023), consumers' attitudes are influenced by many factors, such as health, environmental concerns, perception of food quality, and taste preferences. There is evidence that positive attitudes toward organic foods correlate with the belief that organic foods are healthy, environmentally friendly, tasty, and nutritious (Ham et al., 2018; Sultan et al., 2020; Johe and Bhullar., 2016). According to Basha et al. (2015), among the several compelling reasons mentioned above, product quality also contributes to consumers' attitudes toward purchasing organic food. However, Siripipatthanakul et al. (2022) suggest that apart from health considerations, product information, affordability, and trust are the factors that explain consumers' intention to buy organic food products. Their study also identified that attitudes toward organic food significantly influence the intention to buy organic food among the three TPB constructs. This is because when consumers have positive attitudes towards organic food based on the factors discussed, that may lead to their willingness to purchase organic food

products (Salleh et al., 2010) and possibly increase loyalty and retention (Dagevos & Voordouw, 2013). Hence the following hypothesis:

**Hypothesis 1.** *Respondents' ATT towards CEA influences their intent to consume CEA-grown products.*

Even though a previous study by Siripipatthanakul et al. (2022) suggests that attitude is the most significant influence on consumers' intention, a current study conducted by Tunca et al. (2024) identified subjective norms as the strongest predictor of consumer intention, indicating that this significant influence is as a result of social pressure on purchasing decisions. As explained by Saxena and Vij (2023), subjective norms regarding organic food consumption are influenced by family, friends, and other members of one's social network. They further stated that cultural factors can also play a key role in subjective norms. However, these factors vary according to the region and community. Therefore, in a community where organic food is seen as a luxury item (Hugher et al., 2007), consumers may be influenced to purchase and consume organic food products to show their social status, leading to a higher prevalence of consumption. Additionally, cultural norms encouraging healthy eating habits may impact consumers' organic food purchases (Thøgersen, 2009; Li et al., 2016). Good marketing campaigns are also identified as a factor in shaping consumers' subjective norms in accepting organic food (Saxena & Vij (2023). For example, organic food marketing emphasizes health, and environmental concerns can influence consumers and drive the demand for organic food products (Asioli et al., 2017). Therefore, we propose the following hypothesis:

**Hypothesis 2.** *Respondents' SN towards CEA influences their intent to consume CEA-grown products.*

As reported by Scalco et al. (2017), perceived behavioral control (PBC) has a limited role in predicting intentions compared to attitude and subjective norms. However, they found variation in the results on the strength of PBC to predict consumers' intention to purchase organic food. This is primarily based on the perceived barriers and perceived ability shaping PBC, which in turn influences consumers' organic food buying behavior (Thøgersen, 2009). Evidence shows that perceived barriers to organic food consumption, such as premium price and availability, are significant limiting factors (Padel & Foster, 2005; Hughner et al., 2007; Rodri'guez et al., 2008). On the other hand, perceived abilities such as income or financial resources have been identified as important determinants of consumers' willingness to purchase organic food (Gracia & de Magistris, 2007; Zepeda & Li, 2007; Riefer & Hamm, 2008). Studies have shown that available products, affordable prices, convenience, and organic food knowledge and awareness can positively impact perceived behavioral control (Magnusson et al., 2003; Asioli, 2017). Saxena and Vij (2023) noted that consumers would be willing to purchase organic food if they find it cheap, easily accessible, and widely available. Also, properly communicating the benefits of organic food for consumers can increase their behavior toward purchasing organic food products (Saxena & Vij, 2023). However, to examine PBC in the context of CEA, a hypothesis is proposed as follows:

**Hypothesis 3.** *Respondents' PBC towards CEA influences their intent to consume CEA-grown products.*

## **2. Materials and Methods**

### *2.1. Research Design*

Quantitative research was designed and used to address the research hypothesis. The study focused on adult consumers in the United States. A sample framework was developed

based on non-probability opt-in sampling methods identified in the literature (see Lamm & Lamm 2019). Following human research principles, IRB sought and obtained approval from the University of Georgia Institutional Review Board (IRB: STUDY00008659). A criterion was then established for respondent inclusion according to the demographic distribution identified from the U.S. Census. This study used data collected as part of a larger research study, which is disclosed based on recommendations for clarity in the literature (see Kirkman & Chen 2011).

Respondents were provided with the following definition of Controlled Environment Agriculture (CEA): CEA is the production of agricultural crops (such as plants like tomatoes) grown indoors. Examples of controlled environment systems include greenhouses, vertical agriculture, hydroponics, aquaponics, and other controlled production methods which always exist under modified, highly controlled conditions. Respondents were then asked a set of attention filter questions to ensure they understood the provided definition (for example, true or false, [CEA] is just like traditional uncontrolled outdoor farming methods). Only respondents who correctly answered the questions were allowed to proceed and respond.

## *2.2. Instrumentation and Data Collection*

The study made use of four constructs: (1) consumers' attitude towards CEA-grown products, (2) consumers' subjective norms towards CEA-grown products, (3) consumers' perceived behavioral control towards CEA-grown products, and (4) consumers' willingness to purchase and consume CEA-grown products.

Consumers' attitudes towards CEA-grown products were measured using a scale adopted from Giampietri et al. (2018) and modified for this study. In this construct, participants were asked to indicate their feelings about the following questions: “Consuming CEA grown products is ...” not gratifying to gratifying, unpleasant to pleasant, not satisfying to satisfying, bad to

good, and not enjoyable to enjoyable. Respondents were to select between 1 and 5 to show which questions are closely related.

The second construct focused on consumers' subjective norms towards CEA-grown products based on an adopted scale from Giampietri et al. (2018). Here, participants were assessed based on a 5-point scale between the following statements: “Most people who are important to me...” don’t think I should consume CEA products to think I should consume CEA products, don’t consume CEA themselves to consume CEA products themselves, don’t want me to consume CEA products to want me to consume CEA products, believe consuming CEA products is bad for me to believe consuming CEA products is good for me, expect me not to consume CEA grown products to expect me to consume CEA grown products, and think consuming CEA grown products is not a responsible choice to think consuming CEA grown products a responsible choice.

For consumers' perceived behavioral control toward CEA-grown products, participants were evaluated based on the same scale adopted from Giampietri et al. (2018) and modified for this study. Participants were asked to select from 1 to 5 between the following questions: “Consuming CEA-grown products is...” not up to me to up to me, hard to easy, expensive to inexpensive, something I can’t do to something I can do, and is not in my control to is in my control.

Finally, consumers' willingness to purchase and consume CEA-grown products was also assessed. The construct included five questions: I intend to consume CEA-grown products in the next six months, I plan to prioritize purchasing CEA-grown products in the next six months, I intend to actively seek out CEA-grown products when shopping in the next six months, I will make an effort to consume more CEA-grown products in the next six months, and I am

determined to include CEA-grown products in my diet in the next six months. Responses were collected on a five-point Likert-type scale ranging from 1 – strongly disagree to 5 – strongly agree.

**Table 11.**

*Cronbach’s Alpha values (N = 776).*

<b>Variable</b>	<b>Alpha</b>
Attitude	0.93
Subjective Norm	0.92
Perceived Behavioral Control	0.80
Intention	0.93

Respondents were asked about demographic factors, including age, gender, the highest level of education, and income. The data were collected in February and March 2025, and 776 responses were received.

### 2.3. Data Analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS), version 29. First, the descriptive statistics of each construct were calculated. Then, the coefficients between the Theory of Planned Behavior (TPB) key variables were determined. Finally, the results of a multiple regression analysis using the Theory of Planned Behavior (TPB) variables—Attitude, Subjective Norm, and Perceived Behavioral Control—to predict an outcome related to the intention to consume CEA-grown produce were also determined.

## 3. Results

### Descriptive Results

**Table 12.***Descriptive Statistics of TPB Variables (N = 776).*

Variable	Min	Max	Mean	SD
Attitude	1.00	5.00	4.09	0.84
Subjective Norm	1.00	5.00	3.56	0.83
Perceived Behavioral Control	1.00	5.00	3.67	0.81
Intention	1.00	5.00	3.13	0.89

### **Relationships Between the Theory of Planned Behavior (TPB) constructs and Intention toward CEA-grown Produce**

Correlation between the Theory of Planned Behavior constructs and intention toward CEA-grown produce was completed. Table 3 provides correlation coefficients between the key constructs of the Theory of Planned Behavior (TPB): attitude, subjective norm, perceived behavioral control, and intention to consume CEA-grown produce.

**Table 13.***Relationships Between Theory of Planned Behavior Variables*

Variable	1	2	3	4
1. Attitude	-			
2. Subjective Norm	.586**	-		
3. Perceived Behavioral Control	.429**	.465**	-	
4. Intention	.448**	.548**	.397**	-

Note: \* $p < .05$ , \*\* $p < .01$

## TPB Constructs and Intention toward CEA-grown Produce

Multiple regression was completed to examine the level at which the TPB constructs predict intention toward CEA-grown produce. Intention toward CEA-grown produce was treated as the dependent variable, and TPB constructs were treated as the independent variables.

Overall, 34% of the variance in intention was explained by the predictor variables ( $R^2 = .34$ ,  $F(3, 772) = 133.29$ ,  $p = .00$ ). The results indicate that all three TPB constructs significantly contribute to predicting intentions to consume CEA-grown produce, as shown in Table 4 below.

**Table 14.**

*Multiple Regression of Theory of Planned Behavior Variables*

Intention to consume CEA-grown produce	<i>B</i>	<i>t</i>	<i>Sig.</i>
Constant	0.337	4.285	0.026
Attitude	0.169	10.227	.000
Subjective Norm	0.418	4.423	.000
Perceived Behavioral Control	0.166	4.285	.000
R		.58	
R <sup>2</sup>		.34	

Note. \* $p < .05$ ; \*\* $p < .01$

## 4. Discussion

The study identified that respondents generally have a positive attitude toward CEA-grown produce, as indicated by the high mean score ( $M = 4.09$ ). However, the relatively low standard deviation ( $SD = 0.84$ ) suggests that responses are not highly dispersed. This finding confirms a previous study by Ares et al. (2021), which identified evidence that consumers overall have a positive perception of the CEA industry. The subjective norm ( $M = 3.56$ ) indicated a

moderate level of social influence on consuming CEA-grown produce, with some variation among respondents, while perceived behavioral control ( $M = 3.67$ ) was moderately positive, with responses showing some variation. It was also identified that the intention ( $M = 3.13$ ) to consume CEA-grown produce was slightly above the midpoint, indicating mixed intentions, with a relatively higher standard deviation ( $SD = 0.89$ ) showing variability among respondents. Overall, the findings suggest that while attitudes toward consuming CEA-grown produce are quite positive, the intentions to engage in it are comparatively lower. This discrepancy may indicate barriers such as external constraints or a gap between favorable attitudes and actual behavioral commitment. These findings support a previous study by Seong et al. (2023), who identified that while there is a general willingness to accept indoor agriculture production, a significant number of consumers remain undecided about their attitudes toward the technology, indicating that positive attitudes do not always lead to strong consumption intentions, reflecting potential barriers such as lack of familiarity or perceived risks.

When the correlational analysis was made to understand the relationship between the key TPB constructs and consumers' behavioral intention to consume CEA-grown produce, it was identified that all relationships are statistically significant ( $p < .01$ ), meaning they are unlikely due to chance. However, the subjective norm was identified to have the strongest correlation with intention, suggesting that social pressures play a key role in shaping consumers' behavioral intentions to consume CEA-grown products. Attitude and perceived behavioral control also contribute significantly to intention but to a lesser extent than subjective norms. This implies that even if consumers have a positive attitude toward CEA-grown produce and they feel capable of consuming it, their actual intentions are more strongly driven by the perceived expectations of others. Therefore, to effectively promote CEA-grown products, strategies should leverage social

norms. This could involve educational campaigns highlighting the benefits of CEA-grown products and endorsements from influential figures to shift societal perceptions and encourage adoption. Conversely, research on organic food purchase intentions found that attitudes toward organic food had the strongest influence, while subjective norms had the lowest influence, indicating that personal attitudes can sometimes outweigh social pressures in determining consumer intentions (Hasan & Suciarto, 2020).

When multiple regression analysis was used to examine the level at which the TPB construct predicts consumers' behavioral intention toward consuming CEA-grown produce, the results indicated that all three TPB constructs significantly contribute to predicting the consumer's behavioral intention toward consuming CEA-grown produce. However, the subjective norm has the strongest effect ( $B = 0.418$ ), followed by attitude ( $B = 0.169$ ) and perceived behavioral control ( $B = 0.166$ ). Additionally, the model had a moderate predictive power ( $R^2 = .34$ ), suggesting that other unmeasured factors influence the outcome. Future research could integrate trust into the TPB construct to enhance its predictability. For instance, trust as an integrated variable in TPB was used in several studies as a critical prerequisite for building consumers' confidence in purchasing and consuming products (Carfora et al., 2019; Rehman et al., 2019; Canova et al., 2020).

Another recommendation for future research is to conduct qualitative studies to uncover specific barriers preventing consumers with positive attitudes from consuming CEA-grown produce, such as misconceptions, lack of awareness, or perceived accessibility issues. Additionally, future studies could investigate factors that influence consumers' perceived behavioral control, such as availability, affordability, and perceived quality of CEA-grown produce, to develop strategies that empower consumers to make desired choices. Future studies

could perform longitudinal research to assess how interventions targeting attitudes, subjective norms, and perceived behavioral control influence purchasing behavior over time. The study focused only on consumers in the US, which provided data that is skewed toward a population of people who are privileged when it comes to the use of technology for farming practices.

Therefore, the findings may not be a true reflection of consumers' perception of CEA-grown produce. Future studies could examine consumers from developing countries with developed countries to identify if they produce the same results or something different.

To create awareness about CEA-grown produce and encourage consumer acceptance, producers and stakeholders should organize community events, farm tours, or cooking demonstrations featuring CEA-grown produce to foster a sense of community and normalize consumption. They can also develop social media campaigns that educate consumers about the benefits of CEA, including sustainability, reduced pesticide use, and year-round availability. Addressing knowledge gaps can positively shift attitudes and perceived behavioral control. Producers need to provide transparent information about the cultivation practices in CEA systems, safety standards, and nutritional benefits to build trust and reduce perceived risks associated with new agricultural technologies. This will help to correct the misconception and misinformation about CEA, which has created uncertainty in the minds of consumers about accepting to consume CEA-grown products. To encourage consumers' confidence in relying on CEA-grown products, there should be an increase in the availability of CEA-grown produce in local markets, grocery stores, and online platforms to make purchasing more convenient. In addition to that, producers should implement competitive pricing or promotions to make CEA-grown produce more attractive, especially to price-sensitive consumers.

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## CHAPTER 6

### SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

#### 1. Summary

The Delphi study identified eight overarching themes (Lamm et al., 2023) encompassing one to ten issues, according to the constant comparative method (CCM) (Glaser, 1965). These emerging themes include diseases and pests, energy, economic considerations, food safety and quality, market dynamics, operations and infrastructure, startup capital, and workforce development. The findings identified seven critical issues that were unanimously agreed upon. The seven critical issues were consolidated into three primary themes identified through the CCM: economic considerations, market dynamics, and workforce. Each main category encompasses various issues that span the consensus spectrum and are interrelated. These data indicate that finding markets' regional specifics, sales price of crops, profitability, energy costs, labor costs, and cost of production significantly impact the controlled environment agricultural industry (Cowan et al., 2022). The study was not without limitations. The results reflected only the views of the expert panel members, suggesting that some issues might have been missed, even though the panel included respected industry leaders. Additionally, the respondents may interpret items generated throughout the process differently, making it impossible to consistently define concepts (e.g., Syed & Hachem, 2019).

The second study uncovered several unexpected findings about how demographic factors affect consumers' views on important CEA issues. First, gender was found to be statistically significant for the control and management of disease and pests but not for the rest of the CEA critical issues. The same trend was observed with educational attainment, where startup capital required was the only critical issue that was statistically significant so far as consumers'

perceptions are concerned. Even with this issue, the effect size was considered negligible (Cohen, 1988). With geographic regions, there were not statistically significant influences on consumers' perceptions of all the CEA issues under study (Broad et al., 2022; Coyle & Ellison, 2017). On the contrary, age differences were identified to have a statistically significant relationship with the perception of all the CEA critical issues, with older respondents rating the CEA issues as more important than younger respondents. Although the study findings are unique in the literature, some limitations were identified. Specifically, the study focused only on consumer perceptions; therefore, the results may not reflect producers' thoughts about CEA critical issues. Additionally, the effect sizes observed in the study were generally small and should, therefore, be interpreted with caution.

Study three identified that potential consumers have a generally favorable attitude toward CEA-grown produce. The study found that all three TPB constructs had a statistically significant relationship with consumers' intention to consume CEA-grown produce (Ajzen, 1991). However, subjective norm ranked highest among the TPB constructs regarding consumers' intention to consume CEA-grown produce (Carfora et al., 2019). Additionally, the study identified that subjective norms directly correlate with consumers' attitudes and perceived behavioral control. Therefore, any effort to promote the CEA industry should focus on influencing consumers' perceptions of CEA-grown products through their social relationships, either through events such as in-person meetings, which might work best for older consumers, or through social media, which younger consumers tend to prefer (Carroll et al., 2022). The study focused only on consumers in the US; therefore, the findings may not reflect consumers' perceptions of CEA-grown produce, particularly those with fewer options and/or resources outside of the US. Future

studies could examine consumers from developing countries with developed countries to identify if they produce the same results or something different.

## **2. Conclusions**

To address the challenges associated with the controlled environment agriculture industry, the Delphi study provided insights into the critical issues that have made it difficult for the industry to be more profitable and possible recommendations to address the challenges (Lamm et al., 2023). The Delphi study pinpointed eight primary themes to categorize and tackle critical issues within the controlled environment agriculture industry. The results also provide a benchmark and foundation for analyzing the critical issues of CEA.

Study two tried to identify consumers' demographic characteristics related to their insights regarding the perceived importance of CEA critical issues. Gender and educational levels were only statistically significant for one critical issue, while region did not significantly influence consumers' perceptions of all the CEA issues under study (Broad et al., 2022). However, age differences were identified to have a statistically significant influence on perceptions of all the CEA critical issues, with older respondents rating the issues as more important than younger respondents.

To better understand consumers' willingness to consume CEA-grown produce, the Theory of Planned Behavior (Ajzen, 1991) was applied to examine consumers' perceptions in the US. The study identified a generally positive attitude toward CEA-grown food. The research indicated that the Theory of Planned Behavior (TPB) elements—attitude, subjective norm, and perceived behavioral control—greatly influence consumers' intention to purchase products grown through Controlled Environment Agriculture (CEA). However, the subjective norm is the most significant (Carfora et al., 2019). This suggests that stakeholders in the CEA industry and

policymakers should focus on promoting the CEA industry by ensuring that consumers are well-informed on CEA's production, systems, and benefits through events and social media platforms.

### **3. Recommendations**

#### *3.1. Recommendations and Implications for Practice*

To address issues with pests and diseases, producers are encouraged to establish physical boundaries to prevent pathogens while using technology to monitor and detect pests and diseases and prevent their spread (Ampim et al., 2022). Renewable energy was recommended as the best solution to several identified themes. Additionally, selecting building materials suitable for the location of a CEA system was recommended as an approach to reducing energy consumption. Adopting a system design advanced in light modules was encouraged to reduce energy demand. To reduce operational costs, it was recommended that the possibility of cost reduction and profitability in CEA production be examined before starting the enterprise (Cowan et al., 2022).

Producers are encouraged to take advantage of the well-documented energy-saving measures to reduce the operating costs of CEA systems. Integrating renewable energy systems into CEA facilities, such as PV arrays and fuel cells, was also recommended (Cowan et al., 2022). To address food safety and quality concerns, it was recommended that proper training of farm workers to uphold personal hygiene, sanitization of facilities, tools, and equipment, as well as strict visitor policies to minimize or reduce the risks, should be encouraged. To ensure that CEA production is profitable, it was recommended that fruit and vegetable crops that are more suitable for indoor cultivation be bred and modified to improve the diversity of CEA production (de Carbonnel et al., 2022). Concerning the CEA potential in U.S. and global markets, especially in the developing world such as Ghana, where energy is costly and consumers' economic

situation will not allow them to pay for the premium prices of CEA, producers should focus on growing herbs and cut flowers, which have a significant market opportunity.

From a practical perspective, producers are encouraged to repurpose abandoned structures and warehouses into CEA systems to reduce startup costs. They are also to integrate an educational component into the CEA business, where they provide job training and skill development for individuals who want to work with them. Producers are also encouraged to engage with policymakers. Working together, producers and policymakers may be able to provide incentives to help reduce operating costs and encourage producers to reduce the price of CEA-grown products.

Given that older consumers perceive CEA issues as more critical, outreach efforts should be tailored to address their concerns, while younger consumers should be targeted with content that increases their interest and awareness of CEA technology (Broad et al., 2022). Policymakers should also work with CEA industry stakeholders to develop regulations and incentives that address consumer concerns (Congreves, 2022). Given that consumer perceptions may differ from those of producers, industry stakeholders should establish collaborative dialogues between consumers and producers.

To create awareness about CEA-grown produce and encourage consumer acceptance, producers and stakeholders should organize community events or cooking demonstrations featuring CEA-grown produce to foster a sense of community and normalize consumption (Coyle & Ellison, 2017). They should also consider developing social media campaigns that educate consumers about the benefits of CEA, including sustainability, reduced pesticide use, and year-round availability. Producers and CEA industry players should think about bringing CEA production systems to the public through, for example, demonstration gardens, mobile

gardens, virtual farm tours, etc. This will reduce negative perceptions of CEA productions and prevent frequent visits to production facilities, minimizing pathogen transfer to farms. Also, CEA systems such as hydroponics, aquaponics, and mushroom indoor farms can be introduced to school farming to help the students understand CEA production. This will allow them to gain knowledge of CEA productions and thus help reduce the negative perceptions associated with CEA-grown produce, such as unnatural.

Producers need to provide transparent information about the cultivation practices in CEA systems, safety standards, and nutritional benefits to build trust and reduce perceived risks associated with new agricultural technologies (Carfora et al., 2019). To encourage consumers' confidence in relying on CEA-grown products, the availability of CEA-grown produce in local markets, grocery stores, and online platforms should increase to make purchasing more convenient. In addition, producers should implement competitive pricing or promotions to make CEA-grown produce more attractive, especially to price-sensitive consumers.

### *3.2. Recommendations and Implications for Future Research*

Future research should explore the use of Q-Methodology to investigate CEA critical issues further. This approach may help to provide a broad perspective of stakeholders in the CEA industry. It will also reveal if there are any differences or other critical issues that were not captured in this study. Future studies could also investigate the perspectives of CEA industry producers in developing countries and countries where CEA is most needed due to their soil quality and extreme weather conditions. This will help to identify if there are different perspectives on what is classified as CEA critical issues in different geographical areas.

Future research should compare these findings with producer perspectives to identify alignment or gaps in understanding and expectations (Walters et al., 2020). Future research

should explore whether direct exposure to CEA facilities (e.g., farm visits, interactive training) influences consumer perceptions differently than theoretical knowledge from educational programs. It would be beneficial to study whether regional infrastructure, climate conditions, or policy environments influence producers' willingness to adopt CEA practices. Future research should also examine whether perceptions of CEA issues change as individuals gain more experience with CEA products. Future studies could analyze how media representation and marketing campaigns impact consumer trust and awareness of CEA (Carfora et al., 2019).

Future research could also integrate trust into the TPB construct to examine consumers' willingness to consume CEA-grown produce. Another recommendation for future research is to conduct qualitative studies to uncover specific barriers preventing consumers with positive attitudes from consuming CEA-grown produce, such as misconceptions, lack of awareness, or perceived accessibility issues. Additionally, future studies could investigate factors influencing consumers' perceived behavioral control, such as availability, affordability, and perceived quality of CEA-grown produce, to develop strategies that encourage consumers to make CEA-oriented purchase and consumption choices. Future research connected to CEA that seeks to address SDG2, particularly in developing and developed countries, should consider assessing the general public's knowledge about CEA systems in various stages of development. For example, case studies can include the Netherlands, Canada, the United States, and Ghana. Lastly, future studies could perform longitudinal research to assess how interventions targeting attitudes, subjective norms, and perceived behavioral control influence purchasing behavior over time.

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APPENDIX A  
INSTITUTIONAL REVIEW BOARD APPROVAL FOR STUDY ONE



Tucker Hall, Room 212  
310 E. Campus Rd.  
Athens, Georgia 30602  
TEL 706-542-3199 | FAX 706-542-5638  
IRB@uga.edu  
<http://research.uga.edu/hso/irb/>

Human Research Protection Program

**NOT HUMAN RESEARCH DETERMINATION**

November 15, 2023

Dear [Kevan Lamm](#):

On 11/15/2023, the Human Subjects Office reviewed the following submission:

Title of Study:	Controlled Environment Agriculture (CEA) Critical Issues: Delphi Analysis
Investigator:	<a href="#">Kevan Lamm</a>
Co-Investigator:	Andrews Idun
IRB ID:	PROJECT00008659
Funding:	Auburn University, Flow Through Sponsor: USDA NIFA, FP ID#: FP00026955

We have determined that the proposed activity is not research involving human subjects as defined by DHHS and FDA regulations. The activity is designed to gather expert feedback for evaluation of grower challenges and contribution to Controlled Environment Agriculture (CEA) design solutions.

University of Georgia (UGA) IRB review and approval is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities are research involving human subjects, please submit a new request to the IRB for a determination.

Sincerely,

Jessica Lasebikan, HRPP Assistant Director  
Human Subjects Office, University of Georgia

APPENDIX B  
INSTITUTIONAL REVIEW BOARD APPROVAL FOR STUDY TWO AND THREE



Tucker Hall, Room 212  
310 E. Campus Rd.  
Athens, Georgia 30602  
TEL 706-542-3199 | FAX 706-542-5638  
IRB@uga.edu  
<http://research.uga.edu/hso/irb/>

Human Research Protection Program

**EXEMPT DETERMINATION**

February 10, 2025

Dear [Kevan Lamm](#):

On 2/10/2025, the Human Subjects Office reviewed the following submission:

Title of Study:	Reimagining controlled environment agriculture in a low carbon world: Public Perceptions
Investigator:	<a href="#">Kevan Lamm</a>
Co-Investigator:	Andrews Idun
IRB ID:	PROJECT00011486
Funding:	USDA NIFA/AUBURN UNIVERSITY
Grant ID:	FP00026955
Review Category:	Exempt 2ii

We have determined that the proposed research is Exempt. The research activities may begin 2/10/2025.

Since this study was determined to be exempt, please be aware that not all future modifications will require review by the IRB. For more information please see Appendix C of the Exempt Research Policy (<https://research.uga.edu/docs/policies/compliance/hso/HRP-033-ExemptResearch.pdf>). As noted in Section C.2., you can simply notify us of modifications that will not require review via the "Add Public Comment" activity.

Before beginning the work of the project, it is your responsibility as the PI to ensure that all activities and materials are compliant with the HRPP, including without limitation the following policies and other requirements: [Exempt Research Policy](#) (this includes that the consent process must comply with the elements in Appendix B of the Exempt Research Policy), [Investigator Training](#), [Participant Selection and Recruitment](#), [Internet Research](#).

In addition, the PI must ensure full compliance with any institutional requirements related to data, materials, and confidentiality. Please initiate any related NDA – Non-Disclosure Agreements, MTA – Material Transfer Agreements, or DUA/DSA – Data Use/Sharing Agreements here: <https://research.uga.edu/gateway/patents-licensing/material-transfer-requests-confidential-disclosure-requests/>. If you have any questions about these agreements, or if any other agreement (such as an MOU or similar) is required for the project, please reach out to Matt Hall, Assistant Counsel for Research, [mattbhal@uga.edu](mailto:mattbhal@uga.edu).

All active Exempt research projects fall under the HRPP Quality Assurance Program and may be randomly selected for audit, observation, and other post-approval monitoring. Failure to comply with the above institutional policies or to respond to post-approval monitoring requests may result in findings of [noncompliance](#) and associated corrective action requirements.

A progress report will be requested prior to 2/10/2030. Before or within 30 days of the progress report due date, please submit a progress report or study closure request. Submit a progress report by navigating to the active study and selecting Progress Report. The study may be closed by selecting Create Version and choosing Close Study as the submission purpose.

In conducting this study, you are required to follow the requirements listed in the Investigator Manual (HRP-103).

Sincerely,

Aisha Bradley, Compliance Professional I  
Human Subjects Office, University of Georgia