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Reasons for the Failure of the Plant Factory Industry

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Abstract

This study aims to explore the reasons for the failure of plant factory operations. Through a literature review, it was found that the reasons for failure include high initial investment and operating & maintenance costs, energy consumption, high technical management requirements, unclear product market positioning and insufficient competitiveness, production efficiency and economies of scale issues, challenges in disease and pest control and plant residues, rising labor costs, and consumer acceptance issues. This study conducted qualitative interviews with experts and scholars in the field of plant factories from the United States, Taiwan, China, and Japan. The results of the study revealed that the reasons for the failure of plant factories include investment and operating costs that are too high, insufficient agricultural knowledge about plant factories, inadequate crop marketing capabilities and low consumer acceptance, lack of sales channels for crops, and limited ability of plant factories to integrate various units and train relevant personnel.

Keyword: Agriculture, Plant Factory Industry, Failure Factors

Introduction

By 2050, the population is expected to reach 8.9 billion and world has to produce 50% more food, thereby requiring an additional arable land that is simply not available (FAO, 2020). Decreased soil productivity, depleted soil nutrient reserves, limited irrigation water availability, and climate change are all factors to consider when implementing these new methods of agriculture. Soil-free cultivation systems could be a way to address these modern challenges. As an alternative to soil-based farming systems, vertical farming techniques could potentially serve as a complementary system to help alleviate the current shortage of fertile arable lands and water (Mir et al., 2022). As global population continues to grow and the impacts of climate change intensify, traditional agriculture faces unprecedented challenges. Against this backdrop, the emergence of plant factories, as an innovative agricultural

production model, has garnered significant attention from both academic and industrial sectors.

The global production of plant-based foods is a significant contributor to greenhouse gas emissions. Plant factories can carry out precise environmental control to achieve a "steady-state mass production" production model, which can avoid agriculture's extreme dependence on the natural environment and enable planned production. The need and importance of vertical farming, Vertical farms will develop compact, self-sufficient ecosystems capable of handling a wide range of tasks, from food production to waste disposal. Vertical farming has many benefits, including the ability to produce food in an eco-friendly and sustainable way, save energy and water, reduce pollution, increase the economy, and provide nutritious food. Climate, pests, nutrients, runoff, contaminated water, and dust have less impact on crops grown in controlled environments (USDA, 2017). On the other hand, indoor farming may provide a better environment for growing food (Mukherji & Morales, 2010). Because indoor farming occurs year-round and is not affected by weather, it has the potential to produce higher yields and become a long-term source of income (Katz & Bradley, 2013). Second, due to climate change, the area of cultivated land has decreased. Flash floods, hurricanes, storms, and droughts have destroyed large tracts of productive farmland, negatively impacting the global economy (Muller et al., 2017; Kalantari et al., 2018) and large tracts of arable land may become unavailable for farming. The government has many mechanisms to provide substantial subsidies for traditional agriculture, such as crop insurance against losses caused by natural disasters.

Third, urban density. Compared with "horizontal" urban agriculture, "vertical" urban agriculture allows more urban activities (including more people, services and amenities) to be carried out on the land (Despommier, 2010). Using a 30-storey building (approximately 100 m high) with a site area of 2.02 hectares, Despommier estimates that a conventional horizontal farm could produce 971.2 hectares of crops. The yield of a single high-rise farm is equivalent to the yield of 480 conventional-level farms, according to the following formula: (FAO, 2013 ; Cho, 2011). Fourth, due to traditional farming methods, the natural environment and human environment are often damaged because they do not receive enough attention (Despommier, 2010; Touliatos et al., 2016). If crops are grown in a controlled indoor environment, the use of pesticides and herbicides that contribute to agricultural runoff pollution can be reduced. Through precise irrigation and efficient scheduling, indoor vertical farming uses less water than traditional agriculture, which uses approximately 10 times as much water (Wood et al., 2001). Fifth, due to rising input costs, the cost gap in traditional agriculture is rapidly narrowing. For example, in urban areas, vertical farms are strategically located to sell their products directly to consumers, thereby reducing costs by 60% (Al-Kodmany, 2016).

Scientists have been working on fine-tuning various aspects of indoor farming, such as light intensity and color, temperature and carbon dioxide concentration in the air, soil and water, and humidity levels (Al-Kodmany, 2016). Local economies can also benefit from vertical farming. Abandoned urban structures can be turned into vertical farms to provide fresh food to underserved communities. Sixth, high-tech vertical farming methods: The goal of urban and vertical farming research is to promote a more sustainable food supply. Advanced agricultural technologies can produce higher yields while consuming relatively less

water compared to traditional agricultural practices (Kalantari et al., 2018). The design and setup of these high-tech farms will provide each plant with precisely measured amounts of nutrients while ensuring that all plants receive optimal light. The farms will not require the use of herbicides and pesticides as they will be grown in a closed-loop system, maximizing nutritional and food value.

By the year 2050, vertical farming is expected to be a modern tool for feeding a large global population. constructing a farm that is close to the people it serves by providing cheaper, organic, disease-free crops while also preserving the limited natural resources (Barui, Ghosh & Debangshi, 2022).

In summary, plant factories play a highly significant role in addressing food shortages caused by climate change. However, past research has predominantly focused on the importance and advantages of plant factories, as well as experimental data related to factors such as lighting, fertilizers, temperature, and humidity control to achieve better planting outcomes. These studies aim to identify the key success factors for plant factories. Nevertheless, operating a plant factory involves numerous challenges and factors that may lead to poor performance. The purpose of this study is to explore the drawbacks and causes of failure in operating plant factories. The findings provide valuable reference points for entrepreneurs and agricultural operators, helping them to avoid failures during the establishment process and improve the success rate of plant factory operations.

Literature Review

Definition of Plant Factories

Plant factories are highly intensive, automated indoor agricultural production systems. They optimize plant growth conditions by precisely controlling environmental parameters. According to Kozai et al. (2015), a plant factory is a closed production system that utilizes artificial light sources, environmental control, and automation technologies to produce high-quality, high-yield plants year-round. Goto (2012) further identifies four key characteristics of plant factories: "fully controllable growth environment," "pesticide-free production," "efficient resource utilization," and "stable output quantity and quality."

Vertical farming involves growing crops throughout a building, such as a skyscraper or an old warehouse, rather than underground, which saves water and eliminates the need for soil. No weather or other natural factors can stop food production on vertical farms. When grown in a controlled environment and environmental factors such as light, humidity, and temperature are continuously monitored and manipulated, a variety of plant species can achieve optimal growth rates year-round (Vertical Farming: Feeding the 21st Century World) (Mir et al, 2022). As the world's urban population grows, so does the need for food security. This is where vertical farming comes into play (Corvalan et al., 2005; Despommier, 2010; Healy & Rosenberg, 2013; Thomaier et al., 2015)

Plant factories not only produce crops, but can also adjust the production of secondary metabolites in crops such as anthocyanins (Lee & Kim, 2014), showing that plant factories can not only "mass-produce" crops, but also "add value" to crops., especially for edible vegetables for patients or related to health care, high quality and pesticide-free are only basic needs. Furthermore, the ingredients in the plants can be further adjusted according to the needs of

the niche market, such as improving antioxidants (Tsormpatsidis et al. 2008) or low potassium (Ogawa et al., 2012), low nitrate (Proietti et al., 2013).

Types of Plant Factories

Vertical farming is the process of growing crops in vertically stacked layers. It often combines soilless farming techniques, such as hydroponics, aquaponics and aeroponics, with controlled environment farming designed to optimize plant growth (Barui, Ghosh & Debangshi, 2022). According to Despommier (2013), plant factories can be broadly classified into two categories:

1. Fully artificial plant factories: Utilizing entirely artificial light sources, these are often constructed in urban centers or industrial areas.
2. Solar-utilization plant factories: Combining natural light with supplementary artificial light sources, these are typically built in suburban or rural areas.

Reasons for the Failure of Plant Factory Operations

The growing demand for natural products and the growing world population have increased the need for controlled cultivation systems using artificial lighting. These systems include greenhouses, growth chambers, and vertical farming. Introducing supplemental light (such as fluorescent, metal halide or high-pressure sodium lighting) to replace and/or simulate outdoor conditions where full-spectrum sunlight provides energy to photosynthetic organisms and increases productivity (Ouzounis, Rosenqvist & Ottosen, 2015). This study discusses the aspects of production, sales and government support.

High Initial Investment and Operating & Maintenance Costs

The construction and operation of plant factories often require substantial capital investment, which is frequently a primary cause of operational failure (Kozai et al., 2019). These significant investments are mainly allocated to four equipment systems:

a. Advanced environmental control systems
b. LED lighting equipment
c. Automated planting systems
d. Precision cultivation systems

In addition, although the imported temperature control and guidance system, for example, can adjust the temperature variable to 0.01 degrees Celsius, which is equivalent to the degree of control of space capsule planting, its contribution to yield is minimal. Moreover, in addition to the high initial construction investment, operating and maintenance costs are also considerable. Research by Shamshiri et al. (2018) indicates that long-term energy consumption, equipment maintenance, labor costs, and technological upgrades all contribute to increasing the operational costs of plant factories, far exceeding those of traditional agriculture. Consequently, many plant factories struggle to achieve profitability in the short term, ultimately leading to failure.

Energy Consumption

The global production of plant-based foods is a significant contributor to greenhouse gas emissions. Indoor vertical farms (IVFs) have emerged as a promising approach to urban agriculture (Parkes, Azevedo, Cavallo, Domingos & Teixeira, 2023). The production and transportation of plant-based food products contribute significantly to greenhouse gas (GHG)

emissions, particularly in urban areas Working to reduce emissions by producing food closer to or within urban centres is a potential solution. Energy consumption is another major challenge facing plant factories today. Graamans et al. (2018) compared resource use efficiency between plant factories and conventional greenhouse cultivation, finding that energy consumption in plant factories is significantly higher than in greenhouses. The main factors contributing to the high energy consumption in plant factories include:

a. 24-hour continuous artificial lighting systems
b. 24-hour continuous environmental control systems (including temperature, humidity, carbon dioxide concentration, etc.)
c. Electricity usage for water circulation and cultivation system operation

Since plant factories need to control lighting, energy consumption has been a bottleneck affecting the operation of plant factories in the past. Lighting accounts for 80% of the entire energy consumption structure, and energy consumption accounts for 25% of the total cost structure of plant factories. In recent years, due to the promotion and application of LED energy-saving light sources and energy-saving measures in plant factories, artificial light energy consumption can be reduced by more than 50%; the use of air conditioning and photosynthesis control modes can reduce cooling energy consumption. Plants are able to sense and process messages from the biotic and abiotic environment to achieve optimal growth and development (Fankhauser & Chory, 1997). Light is one of the most important environmental factors affecting plant development and regulating its behavior (Whitelam & Halliday, 2007). While these factors are essential for maintaining plant factory operations, high energy consumption not only substantially increases operational costs but may also conflict with future sustainability goals, especially in regions where energy sources are primarily fossil fuels. How to improve energy efficiency in plant factories and whether renewable energy can be introduced have become key issues for the future development of plant factories.

High Technical Management Capabilities

Threshold and Shortage of Specialized Talent Plant factories differ from traditional agriculture in their higher complexity of cultivation methods, thus requiring a higher level of cultivation technical management capability. In their research, Benke and Tomkins (2017) summarized that successful plant factories require professionals with relevant interdisciplinary expertise and skills, including:
a. Agricultural and plant science knowledge
b. Basic automation and AI technology
c. Environmental control system management knowledge
d. Data analysis and decision-making abilities

However, the current shortage of specialized talent often becomes a bottleneck in plant factory development, leading to issues such as low operational efficiency of systems, improper growth management of cultivated crops, inability to maintain equipment in a timely manner, and failure to effectively utilize advanced technologies to improve factory production efficiency. Therefore, cultivating and retaining professionals with relevant backgrounds is another challenge that requires particular attention in the development of plant factories.

Unclear Product Market Positioning and Insufficient Competitiveness

Plant factories often fail due to unclear market positioning and insufficient competitiveness of their products, as they tend to cultivate higher-priced crops to offset higher operational costs compared to traditional agriculture and consider profit margins. Kalantari et al. (2018) identified several market environment challenges faced by plant factories:

a. Lack of product diversity: Current plant factories mainly cultivate leafy vegetables, making it difficult to meet consumer expectations for diverse agricultural products.

b. High product prices: To cover high production costs, plant factory products are usually priced higher than traditional agricultural products, reducing market acceptance due to price factors.

c. Competition with other organic products: The concept of plant factory cultivation methods is not widely understood by consumers. Therefore, consumers may choose other organic products available in the market, perceiving them as more natural and more healthy.

In addition, plant factory companies do not understand how the agricultural production and marketing chain operates. The most realistic thing about plant factories is that the vegetables produced cannot be sold smoothly. In Japan, only 30% of plant factories are profitable, and 70% are still losing money. The problems that occur in plant factories are all due to the lack of understanding of how the agricultural production and sales chain operates. They think that sales costs and output can be controlled like traditional factory production. However, today's traditional agricultural operations are based on a sales model with middlemen as the main body, and the products of agricultural products are different. Low sex makes it difficult for plant factories to enter the market with high-priced vegetables. Oh and Lu (2022) further proposed ways to enhance the competitiveness of plant factory products, including developing more high-value-added products, strengthening brand image, educating consumers about plant factories, and optimizing production supply chains to reduce production costs.

Production Efficiency and Economies of Scale Issues

Although plant factories can theoretically implement highly efficient production, it is often difficult to fully meet expectations in actual operations. Avgoustaki and Xydis (2020) identified three efficiency challenges commonly faced by plant factories that fail to meet expectations:

a. Low initial operational efficiency: Newly constructed plant factories require time to accumulate data to optimize production processes and adjust parameters, resulting in low operational efficiency in the early stages.

b. Difficulties in expanding production scale: As plant factories are high-investment-cost industries, it is challenging to rapidly expand scale to achieve economies of scale.

c. Rapid advancement of production technology: Plant factories must constantly invest in updating production technologies, which affects long-term efficiency improvements.

Disease and Pest Control Technology and Plant Residues

Liu et al. (2018) pointed out that although closed environments can theoretically effectively reduce disease and pest risks, there are still three environmental factors that influence this:

a. Different light spectra affect plant growth and pest control differently
b. High humidity environments easily lead to the proliferation of certain pathogens
c. Once pests invade a closed environment, they may spread more rapidly

Therefore, to effectively control the occurrence of diseases and pests, it is necessary to find precise environmental parameters for control and appropriate spectrum management for a comprehensive overall prevention strategy. In addition, Lots of garbage, plant residues, etc can be generated around the buildings with vertical farming (Barui, Ghosh & Debangshi, 2022).

Rising Labor Costs

Most plant factories are designed to be planted in horizontal layers, which requires more energy costs to achieve temperature and humidity cycles; the horizontal arrangement is not ergonomic and greatly affects the production line, significantly increasing labor costs. And killed workforce will be unavailable initially and will need to be trained (Barui, Ghosh & Debangshi, 2022).

Consumer Acceptance Issues

Regarding consumer acceptance of plant factories, Specht et al. (2014) found that consumers have concerns about their products, including:
a. Distrust of "completely artificial" production methods
b. Concerns about the nutritional value and taste of products
c. Worries about the use of LED lights and chemical fertilizers
d. Price sensitivity

The process from product awareness to consumer acceptance is a long journey. Therefore, it is necessary to maintain stable product quality and safety, continuously understand and improve consumer preferences for product taste and appearance, transparently promote production processes to educate consumers, and strive to increase the value-for-money of products.

Interview Analysis

In order to understand the factors that lead to the failure of plant factories, this study interviewed American scholars, Taiwanese scholars, people in charge of plant factories in China, and people in charge of plant factories in Japan. Through interviews, we learned about the common business failures of plant factories in the United States, Taiwan, China, and Japan. factor.

Investment Costs and Operating Costs are too High

American scholars have pointed out that the initial investment costs for plant factory equipment are excessively high, and that electricity and employee wages are significant operational expenses for these facilities. In Taiwan, scholars note that plant factories are primarily funded by technology companies. However, these companies often anticipate strong market demand, leading to excessive investment in plant setup and equipment during the initial stages, which requires larger capital investment. In Japan, the chairman of the Plant Factory Association has observed that the lack of familiarity with plant factory facilities and equipment leads to higher setup costs and extended installation times. For example, according to an assessment by the New Business Development Department of Japan's STANLEY Electric Co., Ltd., the cost structure of a fully artificial-light plant factory includes 20%

for sales and logistics, 8% for material costs, 23% for labor, 22% for facility depreciation, and a high 27% for electricity, making energy expenses a significant barrier to profitability in plant factory operations.

Insufficient Agricultural Knowledge about Plant Factories

Currently, most companies involved in plant factories worldwide are not originally agricultural enterprises. American scholars have noted that companies in this field often lack adequate agricultural knowledge, particularly regarding the optimal conditions for different plants in a plant factory environment, such as temperature, humidity, lighting duration, and nutrient composition. Leaders of Chinese plant factories have emphasized the importance of fully understanding the factors that affect plant growth. For instance, some focus primarily on heating systems, while in reality, lighting plays a crucial role; a well-designed lighting system can stimulate plants to grow taller with larger leaves, which enhances their market value. Furthermore, the purpose of operating plant factories in China lacks clarity. The focus should be on how to provide a stable supply of vegetables to meet market demands, rather than merely viewing plant factories as a production tool.

Inadequate Crop Marketing Capabilities and Low Consumer Acceptance

Taiwanese scholars have pointed out that plant factories in Taiwan are primarily operated by technology companies. However, these companies often lack a thorough understanding of the characteristics of agricultural products. Unlike durable industrial goods, crops are perishable, and if they are not sold at their optimal freshness after harvest, their quality can be significantly compromised. Additionally, if these companies lack effective marketing capabilities, it further hampers the sales of agricultural products. In Japan, consumers are not well-acquainted with the differences between crops grown in plant factories and those cultivated through traditional methods. Coupled with the fact that plant factory produce is priced higher than traditionally grown crops, this has led to low acceptance of plant factory products among Japanese consumers.

Lack of Sales Channels for Crops

Taiwanese scholars mentioned that the failure of plant factories is often due to the lack of sales channels, resulting in limited sales of crops, making it difficult for the company to expand its business scale. The person in charge of the Japanese plant factory also mentioned that if a complete sales channel is not established in Japan, crops cannot be distributed or intensively distributed. Companies that successfully operate plant factories in Japan usually have clear customers and sales channels, such as cooperation with restaurants, schools, supermarkets, chain stores, and crop business platforms. For this reason, if a plant factory does not have a complete sales channel to sell crops, the possibility of failure is extremely high.

Plant Factories Lack the Ability to Integrate Various Units and Cultivate Relevant Personnel

The person in charge of Japanese plant factories believes that plant factories are currently in the early stages of development and lack talents with the ability to integrate factory management, plant equipment construction engineering, business models, etc. Chinese experts and scholars also provide that the business focus of plant factories is often on the equipment or the plants themselves, with less training for personnel. Only good people can continue to improve and think about how to improve plant factory equipment or various

influencing factors, such as lighting time and light waves fertilizers, etc. To make crops grow better.

Conclusion

Plant factory is an innovative way of agricultural production. Although their development theory and concepts have many potential and practical advantages, they still face many operational and technical challenges. High investment costs, high energy consumption, high technical thresholds, unclear market positioning, insufficient production efficiency, concerns about pest and disease control, and consumer acceptance of products may all lead to the failure of plant factories. To overcome and solve these problems, industry players must continuously invest in technology research and development, optimize management processes, expand product markets, and educate consumers. Only when these aspects go hand in hand can plant factories truly realize and realize their advantages and development potential in modern and future agriculture.

Since plant factories are a high-input, high-output production method that requires a large amount of capital investment, it is best to receive support from government policies or funds in the early stages of development. For example, in terms of fiscal and financial policies, policy subsidies and tax exemptions can be provided to agricultural technology product R&D and application entities, network access, data transmission and communication costs can be reduced, and energy consumption costs can be reduced. operations and provide diversified financing tools. The conclusions of this study are highly practical for businesses and agribusinesses entering or operating plant factories, as they help reduce the likelihood of failure. This enables plant factories to move toward sustainable development and address the global food issue, thereby maintaining a balance in agricultural production and supply.

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