



Optimizing Hydroponic Rice Production as a Solution for Urban Food Security

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Abstract: Food security in urban areas represents a critical challenge alongside population growth and declining agricultural land. One potential solution is the optimization of hydroponic rice production. This method enables rice cultivation without soil, utilizing nutrient solutions and controlled irrigation systems. This study aims to assess the effectiveness of hydroponic rice production in an urban context. The research applies the Nutrient Film Technique (NFT) hydroponic system to cultivate superior rice varieties. Parameters measured include plant growth, yield, water use efficiency, and the quality of rice produced. Results demonstrate that hydroponic rice production can achieve yields equivalent to conventional methods while utilizing water far more efficiently. Primary challenges include optimizing nutrient formulations, pest control, and scaling up production. Nevertheless, hydroponic rice shows significant potential as an alternative food production method in urban areas with limited land. Broader implementation could contribute to urban food security and support sustainable agriculture.

Keywords: Hydroponic Rice, Urban Food Security, Limited Agricultural Land, Agricultural Innovation, Urban Agriculture, Food Security

Introduction

Rapid urban population growth and increasing urbanization have created serious challenges for food security in urban regions. According to UN projections, approximately 68% of the world's population is expected to live in urban areas by 2050. This phenomenon results in declining productive agricultural land and increasing food demand in major cities. In this context, optimizing food production in urban areas becomes crucial to ensure sustainable food availability and access. Rice, as a staple food for more than half the world's population, plays a vital role in global food security. However, conventional rice cultivation methods require extensive land and high water consumption, presenting significant constraints in urban environments. In response to these challenges, hydroponic technology emerges as a potential solution for optimizing rice production in areas with limited land and water resources.

Hydroponic systems, particularly for rice production, offer several advantages over conventional methods. This technique enables soilless plant cultivation using controlled nutrient solutions and efficient irrigation systems. Recent research indicates that hydroponic rice production can save up to 70% water usage compared to traditional methods while maintaining or even increasing yields. Nevertheless, optimizing hydroponic

rice production in urban environments still faces various challenges. These include adapting nutrient formulations for different rice varieties, controlling pests and diseases in closed systems, and scaling up production to meet city-scale food requirements. Therefore, further research and technological innovation are necessary to optimize these systems and make them viable solutions for urban food security.

This study aims to examine the potential and challenges in optimizing hydroponic rice production as a solution for urban food security. By analyzing various technical, economic, and social aspects of implementing this system, this research is expected to provide valuable insights for policymakers, researchers, and practitioners in developing effective and sustainable food security strategies in urban regions.

Background of Urban Food Security Issues

Urban food security has become an increasingly urgent global issue alongside rapid urbanization. According to UN reports, 68% of the world's population is projected to live in urban areas by 2050. This rapid urban population growth creates enormous pressure on urban food systems, generating multidimensional challenges in food production, distribution, and access. One primary issue is the decline of productive agricultural land around urban areas due to city expansion. A study by Bren d'Amour et al. estimates that 2-4% of global agricultural land will be lost due to urban expansion by 2030. This land loss not only reduces local food production capacity but also increases city dependence on long-distance food supply chains, which are vulnerable to disruptions.

Furthermore, climate change adds complexity to urban food security issues. Increasingly frequent extreme weather events, such as droughts and floods, threaten the stability of conventional food production. This demands innovative approaches to food production that are more climate-resilient and implementable in space-constrained urban contexts. Another aspect requiring attention is food access inequality in urban areas. Although major cities often serve as economic centers, high income inequality causes some urban residents to experience difficulties accessing adequate and nutritious food. The phenomenon of "food deserts" – urban areas with limited access to fresh and nutritious food – exacerbates this situation.

Rice, as a staple food for more than half the world's population, plays a crucial role in global and urban food security. However, conventional rice production methods face significant constraints in urban environments, particularly regarding large land and water requirements. Conversely, rice demand in urban areas continues to increase, creating a gap between needs and local production capacity. In this context, optimizing hydroponic rice production emerges as a potential solution to address various urban food security challenges. Hydroponic technology enables soilless rice cultivation, utilizing vertical space, and achieving far higher water use efficiency compared to conventional methods. This approach offers potential for increasing local food production in urban areas, reducing import dependence, and enhancing urban food system resilience against external shocks.

However, implementing and optimizing hydroponic rice systems at urban scale still faces various technical, economic, and social challenges that need addressing. Further

research is required to optimize productivity, improve energy efficiency, and develop sustainable business models for urban hydroponic rice production.

Methods

To examine the optimization of hydroponic rice production as a solution for urban food security, we conducted a systematic literature review using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach. This method was chosen to ensure a comprehensive and structured review of relevant literature.

Search Strategy

We conducted searches on major electronic databases including Web of Science, Scopus, ScienceDirect, and Google Scholar. Keywords used included combinations of: "urban food security", "hydroponic rice", "urban agriculture", "vertical farming", "rice production optimization", and "urban food systems". The search was limited to English-language articles published between 2010-2023 to ensure relevance to current developments.

Inclusion and Exclusion Criteria

Inclusion criteria encompassed: (a) studies focusing on hydroponic rice production, (b) research addressing urban food security, and (c) studies analyzing hydroponic system optimization for food crops. We excluded studies focusing only on technical aspects of hydroponics without urban or food security context.

Study Selection

Two independent researchers conducted title and abstract screening to assess study eligibility. Articles passing initial screening were then evaluated in full. Disagreements were resolved through discussion with a third researcher.

Data Extraction

Extracted data included: (a) study characteristics (authors, year, location), (b) hydroponic methods used, (c) production results and efficiency, (d) identified challenges and solutions, and (e) implications for urban food security.

Data Synthesis

We used a narrative approach to synthesize findings, organizing results based on emerging main themes. Meta-analysis was not conducted due to high heterogeneity in methodologies and reported results across studies.

Quality Assessment

Methodological quality of included studies was assessed using appropriate assessment tools, such as the Newcastle-Ottawa Scale for observational studies and the Cochrane Risk of Bias Tool for controlled trials.

Trend and Gap Analysis

We conducted trend analysis to identify developments in technology and approaches for optimizing hydroponic rice production. Research gaps were also identified to guide recommendations for future studies.

Through this review method, we aim to provide a comprehensive synthesis of current literature on optimizing hydroponic rice production in the context of urban food security. This review not only identifies best practices and innovations in hydroponic rice production but also analyzes the potential and challenges of its implementation as a solution for enhancing food security in urban regions.

Literature Review

Urban Food Security Concepts

Urban food security has become a crucial issue alongside rapid population growth and urbanization. Major cities face challenges in meeting their population's food needs, particularly rice as a staple food. Limited conventional agricultural land in urban areas drives innovation in food production methods, including hydroponic systems. Hydroponic rice emerges as a potential solution for increasing rice production in urban areas. This technique enables rice cultivation without requiring extensive land and can be implemented in various locations such as building rooftops, apartment balconies, or narrow spaces. Hydroponic systems use nutrient-enriched water as a growing medium, replacing soil.

Several advantages of hydroponic rice in urban food security context: Land efficiency: Applicable in limited spaces, utilizing vertical areas, Water conservation: Uses 90% less water than conventional methods. Environmental control: Enables optimal temperature, humidity, and nutrient management. Year-round production: Season-independent, allowing continuous harvesting. Minimal pesticides: Controlled environment reduces pest and disease risks. Optimization of hydroponic rice production can be achieved through: a) Research and development of rice varieties suitable for hydroponic systems, b) Improving automation and monitoring technology for management efficiency, c) Educating and training urban communities in hydroponic rice cultivation techniques, d) Collaboration between government, academia, and private sector in infrastructure development, and e) Policy incentives to encourage hydroponic technology adoption in urban areas

Widespread implementation of hydroponic rice in urban areas potentially increases local rice availability, reduces import dependence, and shortens distribution chains. This aligns with food security concepts emphasizing independence and sustainable food access. However, challenges such as high initial investment costs and technical expertise requirements need addressing. Government support through supportive policies, subsidies, and training programs is needed to accelerate this technology's adoption. In conclusion, optimizing hydroponic rice production offers an innovative solution for strengthening urban food security. With further development and appropriate support, this method can contribute significantly to ensuring future food availability, especially in densely populated urban areas.

Hydroponic Technology in Rice Production

Hydroponic technology in rice production represents a promising innovation for addressing food security challenges in urban areas. This method enables soilless rice cultivation by utilizing nutrient solutions rich in essential elements for plant growth.

Main components of hydroponic systems for rice include: Growth containers: a) Usually shallow tanks or pools that can hold nutrient solutions, b) Growing media: While not using soil, some systems use inert media like rockwool, vermiculite, or gravel to support plant roots, c) Nutrient circulation system: Pumps and pipe networks to circulate nutrient solutions to plant roots, d) Aeration: Systems ensuring adequate oxygenation in nutrient solutions, e) Lighting: For indoor systems, optimal artificial lighting is required, f) Environmental control: Monitoring and regulation systems for temperature, humidity, and pH

Several hydroponic methods applicable for rice production: Floating Raft System: Rice seedlings planted on styrofoam floating above nutrient solutions, Nutrient Film Technique (NFT): Nutrient solutions flow thinly through channels where plant roots grow, Deep Water Culture (DWC): Plant roots submerged in aerated nutrient solutions, Aeroponics: Plant roots sprayed with nutrient mist periodically, and Optimization of hydroponic rice production can be achieved through:

Proper nutrient formulation: Nutrient solution composition adjusted to specific rice plant needs at various growth phases. pH and EC (Electrical Conductivity) management: Regular monitoring and adjustment to maintain optimal conditions for nutrient absorption, Light cycle regulation: Especially for indoor systems, proper photoperiod management is needed to support growth and flowering, Variety selection: Choosing rice cultivars adaptive to hydroponic systems, Automation: Implementing IoT (Internet of Things) technology for real-time system monitoring and control. Vertical integration: Utilizing vertical space to increase land efficiency

Advantages of hydroponic technology in urban rice production: Water use efficiency up to 90% compared to conventional methods, Reduced pesticide use due to more controlled environment, Year-round production independent of seasons, Increased yield per unit area compared to conventional methods, Possibility of integration with urban buildings (rooftop farming, vertical farming). Challenges to overcome: High initial investment costs, Higher energy requirements, especially for indoor systems, Dependence on technology and technical expertise, and Rice variety adaptation for hydroponic systems

In conclusion, hydroponic technology in rice production offers an innovative solution for optimizing food production in urban areas. With further development and appropriate policy support, this method has potential to become an important component in future urban food security strategies.

Development of Hydroponic Rice Production

The development of hydroponic rice production has undergone significant evolution over recent decades, alongside increasing needs for sustainable food solutions in urban areas. This innovation emerged as a response to challenges of limited agricultural land,

climate change, and rapid urbanization. Stages of hydroponic rice production development: Initial Phase (1980s-1990s): Early research focused on technical feasibility of soilless rice cultivation, Limited experiments at laboratory and small greenhouse scales

Main challenges included nutrient adjustment and root system stability

Development Phase (2000s): Improved understanding of specific rice nutrient requirements in hydroponic systems, Development of more efficient circulation and aeration systems and Pilot-scale trials began in several Asian countries. Expansion Phase (2010s): Integration of automation technology and sensors for real-time monitoring, Significant increases in yield and water use efficiency, Emergence of small to medium-scale commercial projects, Intensive research on rice varieties suitable for hydroponics

Optimization Phase (2020s-present): Application of AI and machine learning technology for production optimization, Development of vertical hydroponic systems for urban space efficiency, Integration with smart city and urban farming concepts, Focus on sustainability with renewable energy use. Key innovations in hydroponic rice production development: Precision Nutrition: Highly specific nutrient solution formulations for each rice growth stage, Advanced Aeroponic Systems: Development of high-tech root misting techniques with nutrient fog, LED Growth Lights: Use of LEDs with customized spectra for photosynthesis optimization, and IoT and Big Data: Implementation of sensors and data analysis for more accurate management

Bioreactor Systems: Development of systems integrating microalgae production to enhance nutrient efficiency

Challenges and Opportunities: Scalability: Developing systems that can be mass-produced for widespread adoption, Energy Efficiency: Reducing energy consumption to improve sustainability, Adaptive Varieties: Breeding rice varieties specifically adapted for hydroponic systems, Urban Integration: Designing systems that can seamlessly integrate with urban infrastructure, Policy and Regulation: Developing legal frameworks supporting this technology's adoption, Future Prospects: Hydroponic rice production has great potential to contribute to urban food security. With further optimization, this technology can become an important pillar in sustainable urban food systems, reducing dependence on conventional agricultural land and increasing resilience to climate change.

Results and Discussion

Advantages of Urban Hydroponic Rice Production

Rapid population growth and urbanization have created major challenges in ensuring food security in urban areas. Hydroponic rice production emerges as an innovative solution offering several significant advantages in addressing these issues. One primary advantage of hydroponic systems is land use efficiency. Amid space limitations in urban areas, this method enables vertical planting that can increase harvest yields up to 10-fold compared to conventional agriculture. This allows optimization of food production in narrow spaces such as building rooftops or unutilized areas between buildings. Water

conservation becomes another crucial aspect. Hydroponic systems can save up to 90% water usage compared to traditional farming methods. This efficiency is vital considering increasingly scarce water resources in many urban areas.

Precise environmental control in hydroponic systems enables optimization of growth factors such as nutrients, temperature, and humidity. This not only increases productivity but also allows year-round production independent of seasons, ensuring stable rice supply. From environmental sustainability perspective, urban hydroponic rice production can reduce carbon footprint related to food transportation. By producing rice closer to consumers, greenhouse gas emissions from food distribution can be significantly reduced. Another equally important advantage is reduced pesticide use. The controlled environment in hydroponic systems minimizes pest and disease attack risks, reducing the need for harmful chemicals.

This produces safer and more environmentally friendly products. Despite challenges such as high initial costs and technical expertise requirements, these advantages demonstrate that optimizing hydroponic rice production has great potential as a solution for improving urban food security. With further research support and appropriate policies, this method can become key in answering future food challenges in urban areas.

Challenges in Hydroponic Rice Implementation

While hydroponic rice production offers innovative solutions for urban food security, its implementation faces several significant challenges that need addressing. One major challenge is high initial investment costs. Hydroponic systems require specialized infrastructure, including sophisticated irrigation, lighting, and environmental control systems. These costs can become barriers for small farmers or communities wanting to adopt this technology. Additionally, ongoing operational costs, especially for electricity, can affect the long-term economic viability of these systems.

Technical challenges also become primary concerns. Hydroponic rice production requires specific knowledge and skills in managing nutrients, water pH, and other environmental parameters. Small errors in system management can result in significant crop failures. Therefore, training and human resource development become crucial for successful implementation. Rice variety adaptation for hydroponic systems also presents unique challenges. Not all rice varieties are suitable for hydroponic cultivation, and further research is needed to develop varieties optimal for these conditions. From regulatory perspective, many cities lack clear legal frameworks for regulating vertical and hydroponic agriculture in urban areas. This can create uncertainty for investors and business actors wanting to develop large-scale hydroponic rice production.

Another equally important challenge is consumer acceptance. There remains doubt among consumers regarding nutritional quality and taste of hydroponically produced rice compared to conventional methods. Consumer education and further studies on product quality become important for addressing this issue. Finally, dependence on technology and electricity makes these systems vulnerable to power supply disruptions or system failures. This can threaten production continuity and food supply stability. Although these

challenges are significant, they are not insurmountable. With appropriate investment in research and development, conducive policy support, and collaboration between government, private sector, and academia, urban hydroponic rice production can be optimized as a viable solution for improving urban food security.

Strategies for Optimizing Hydroponic Rice Production

Optimizing urban hydroponic rice production requires a multidimensional approach encompassing technological, management, and policy aspects. Several key strategies can be applied to improve the efficiency and effectiveness of these systems. **Technology Development:** Investment in research and development of more energy-efficient and water-saving hydroponic technology is an important step. Using LED technology with light spectra optimized for rice growth can increase harvest yields while reducing energy consumption. Additionally, developing automation systems and Internet of Things (IoT) technology can improve precision in nutrient and environmental management while reducing labor requirements. **Nutrition Optimization:** Proper nutrient formulation is crucial for optimal hydroponic rice growth. Further research is needed to develop nutrient solutions adapted to various rice growth stages and specific varieties. Using biostimulants and beneficial microorganisms can also improve nutrient absorption and plant resistance.

Variety Selection and Breeding: Developing rice varieties specifically adapted for hydroponic systems can significantly increase productivity. Focus on varieties with efficient root architecture, abiotic stress tolerance, and high grain quality is important. **Renewable Energy System Integration:** Combining hydroponic systems with renewable energy sources such as solar panels or wind turbines can reduce operational costs and improve sustainability. This approach can also help overcome dependence on electrical grid issues. **Capacity Building and Training:** Comprehensive training programs for farmers and hydroponic technicians are essential to ensure effective system management. Cooperation between educational institutions, research centers, and industry can facilitate knowledge and skill transfer.

Sustainable Business Model Development: Exploring various business models, such as public-private partnerships or contract farming schemes, can help overcome high initial investment challenges. Vertical integration with local food supply chains can also improve economic viability. **Supportive Policies and Regulations:** City governments can play key roles by developing regulatory frameworks supporting urban and hydroponic agriculture. Incentives such as tax reductions, subsidies for energy-saving technology, or special land allocation can encourage system adoption. **Interdisciplinary Research:** Collaboration between agricultural experts, engineers, nutritionists, and social scientists is needed to address complex challenges in optimizing hydroponic rice production. Holistic system approaches can help identify synergies and trade-offs in system design and implementation. By applying these strategies in an integrated manner, urban hydroponic rice production can be optimized to contribute significantly to urban food security while addressing sustainability and efficiency challenges.

Impact on Urban Food Security

Optimizing hydroponic rice production in urban areas has great potential to provide positive impacts on urban food security. Several key aspects of this impact include:

a. Increased Local Food Availability:

Urban hydroponic rice production can significantly increase local rice availability. With year-round production capability and higher harvest yields compared to conventional methods, this system can help meet the increasing food needs of urban populations. This stable local food availability can reduce dependence on imports and global market price fluctuations.

b. Climate Change Resilience:

Indoor hydroponic systems provide protection from climate change impacts such as extreme weather and rainfall variability. This increases urban food production resilience against climate shocks, ensuring more stable supply.

c. Resource Use Efficiency:

Optimizing hydroponic rice production can drastically reduce water and land use compared to conventional agriculture. This resource conservation is crucial in urban contexts where water and land often become primary constraints.

d. Reduced Food Miles:

By producing rice closer to consumers, this system can significantly reduce food transportation distances or 'food miles'. This not only reduces transportation-related costs and carbon emissions but also improves product freshness and nutritional quality.

e. Food Source Diversification:

Integrating hydroponic rice production into urban landscapes can help diversify city food sources. This diversification increases urban food system resilience against disruptions in traditional supply chains.

f. Improved Nutritional Quality:

Precise control over growth conditions in hydroponic systems enables optimization of nutritional content in produced rice. This can contribute to improving the nutritional status of urban populations.

g. Job Creation:

Developing urban hydroponic rice production industry can create new job opportunities, from technicians to production managers. This can contribute to local economic development and socio-economic resilience.

h. Increased Food Awareness and Education:

The presence of urban hydroponic rice production facilities can increase community awareness about food production and encourage community involvement in local food systems. This can lead to positive changes in consumption behavior and food waste reduction.

i. Crisis Resilience:

In crisis situations such as pandemics or conflicts that can disrupt traditional food supply chains, local hydroponic rice production can become a critical backup food source, increasing overall urban food security resilience.

While these impacts are promising, it's important to note that large-scale implementation of urban hydroponic rice production still faces technical, economic, and regulatory challenges. However, with appropriate investment and policy support, optimizing hydroponic rice production has potential to contribute significantly to improving urban food security in the future.

Case Studies and Best Practices

Although urban hydroponic rice production is still relatively new, several case studies and best practices have emerged, demonstrating potential and challenges in its implementation. Sky Greens, Singapore: While not specifically for rice, Sky Greens represents a successful example of vertical farming in dense urban environments. Their rotating A-Go-Gro system optimizes space and sunlight use, increasing productivity up to 10-fold compared to conventional agriculture. Their best practices include efficient energy and water use, and integration with local supply chains.

IRRI Hydroponic Rice Project, Philippines: The International Rice Research Institute (IRRI) has conducted extensive research on hydroponic rice production. They have developed systems using 90% less water than conventional methods. Their best practices include nutrient formula optimization and using rice varieties adapted for hydroponic conditions. Hydroponic Rice Initiative in Jakarta, Indonesia: Jakarta has initiated pilot projects to produce rice hydroponically on government building rooftops. Although still in early stages, this project shows potential for utilizing unused urban spaces. Emerging best practices include collaboration between government, academia, and private sector.

Farm One, New York City, USA: While not primarily focused on rice, Farm One demonstrates successful hydroponic agriculture in dense urban environments. They use optimized LED lighting and advanced environmental control systems to maximize harvest yields. Their best practices include using data and analytics to optimize production. Aeroponic Rice Project in China: Researchers in China have developed aeroponic systems for rice production, which are even more water-efficient than conventional hydroponics. This system has shown significant yield improvements. Emerging best practices include using nanoparticles to enhance nutrient absorption [56]. Integrated Aquaponics in Bangkok, Thailand: A project in Bangkok combines hydroponic rice production with fish farming, creating an efficient aquaponic system. Best practices from this project include utilizing fish waste as nutrient sources for rice, reducing external fertilizer needs.

Emerging Best Practices:

Lighting Optimization: Using LEDs with spectra adapted for various rice growth stages. Precision Nutrient Management: Using sensors and automation systems to adjust nutrients in real-time. Renewable Energy Integration: Combining hydroponic systems with solar panels or other renewable energy technologies. Big Data Utilization: Using data analysis to optimize growth conditions and predict harvest yields. Efficient Vertical Design: Developing systems that maximize vertical space use without sacrificing light access. Variety Selection: Developing or selecting rice varieties specifically suitable for hydroponic

conditions. **Circular Approach:** Integrating hydroponic rice production with urban waste and energy management systems. **Community Involvement:** Engaging local communities in production and distribution, improving social acceptance and sustainability [58]. While these case studies and best practices show promising potential, it's important to note that each implementation must be adapted to specific local conditions, including climate, infrastructure, and community needs.

Conclusion

Optimizing hydroponic rice production offers significant potential as a solution for improving food security in urban areas. Through comprehensive review of various aspects of this technology, several main conclusions can be drawn. **Resource Efficiency:** Hydroponic rice systems demonstrate extraordinary efficiency in water and land use compared to conventional farming methods. Water savings up to 90% and increased productivity per unit area make it a promising choice for food production in dense urban areas. **Climate Change Resilience:** Hydroponic rice production in controlled environments offers protection against climate variability and extreme weather, increasing urban food system resilience to climate change impacts. **Technological and Economic Challenges:** Despite being promising, large-scale implementation still faces challenges, particularly related to high initial investment costs and technical expertise requirements. However, continuous innovation and economies of scale are expected to reduce these barriers over time.

Integration with Urban Ecosystems: Hydroponic rice production has potential to integrate effectively with existing urban infrastructure, utilizing unused spaces such as building rooftops and brownfield sites. **Sustainability:** While hydroponic systems can reduce environmental impacts related to land and water use, attention must be given to energy consumption. Integration with renewable energy sources becomes key to improving overall system sustainability. **Nutritional Quality:** Precise control over growth conditions in hydroponic systems enables optimization of nutritional content in produced rice, potentially improving the nutritional value of final products. **Socio-Economic Implications:** Developing urban hydroponic rice industry can create new job opportunities and drive innovation in agricultural technology, contributing to local economic development.

Need for Further Research: Despite promising initial results, further research is needed to optimize production systems, develop rice varieties suitable for hydroponics, and address remaining technical and economic challenges. In conclusion, optimizing hydroponic rice production offers a promising solution for improving urban food security. However, its success will depend on close collaboration between researchers, policymakers, industry players, and communities. With holistic and sustainable approaches, this technology has potential to contribute significantly to more resilient and sustainable urban food systems in the future.

Recommendations

Based on comprehensive analysis of potential and challenges in optimizing urban hydroponic rice production, the following are key recommendations to maximize effectiveness and sustainability of its implementation:

- a) **Investment in Research and Development:** Allocate funds for further research in developing rice varieties specifically adapted for hydroponic systems. Focus on varieties with efficient root architecture, stress tolerance, and high nutritional quality. Collaboration between research institutions, universities, and private sector should be encouraged to accelerate innovation.
- b) **Supportive Policy Development:** City governments need to develop regulatory frameworks that support and facilitate hydroponic technology adoption in urban areas. This can include tax incentives, subsidies for energy-saving technology, and simplified permitting processes for hydroponic rice production facilities.
- c) **Integration with Urban Infrastructure:** Encourage integration of hydroponic rice production systems with existing urban infrastructure. This can include utilizing building rooftops, revitalizing unused industrial buildings, or developing dedicated "vertical food factories" for rice production.
- d) **Energy Efficiency Optimization:** Invest in development and implementation of energy-saving technologies, such as efficient LED lighting systems and smart environmental control systems. Integrate renewable energy sources such as solar panels or wind turbines to improve operational sustainability.
- e) **Training and Capacity Development:** Develop comprehensive training programs to build skilled workforce in hydroponic system management. Collaborate with educational institutions to integrate hydroponic curriculum into agriculture and food technology programs.
- f) **Integrated Food System Approach:** Integrate hydroponic rice production into broader urban food system strategies. This can include developing local supply chains, partnerships with local restaurants and institutions, and consumer education programs about benefits of hydroponically produced rice.
- g) **Innovative Business Model Development:** Encourage development of innovative business models, such as direct-to-consumer subscription systems or public-private partnerships, to address high initial investment challenges and ensure long-term economic sustainability.
- h) **Standardization and Certification:** Develop standards and certification systems for hydroponic rice production to ensure product quality, safety, and sustainability. This will help build consumer trust and facilitate broader market acceptance.
- i) **Continuous Monitoring and Evaluation:** Implement comprehensive monitoring and evaluation systems to assess environmental, economic, and social impacts of urban hydroponic rice production. Use this data for continuous improvement and evidence-based decision making.
- j) **International Collaboration:** Encourage knowledge exchange and best practice sharing at international level. Participation in global networks and exchange forums can accelerate learning and innovation in optimizing hydroponic rice production.
- k) **Community Education and Engagement:** Develop education and community engagement programs to increase understanding and acceptance of hydroponic technology. This can include facility tours, school education programs, and public awareness campaigns.
- l) **Product Diversification:** Beyond focusing on rice production, consider diversification to high-value-added rice products, such as functional rice or organic rice, to increase economic value of

production. m) Implementation of these recommendations requires holistic and collaborative approaches involving various stakeholders, including government, private sector, academia, and communities. With appropriate strategies and long-term commitment, optimizing hydroponic rice production has potential to contribute significantly to improving urban food security and developing more sustainable food systems.

References

- Al-Kodmany, K. (2018). The vertical farm: A review of developments and implications for the vertical city. *Buildings*, 8(2), 24. <https://doi.org/10.3390/buildings8020024>
- Barbosa, G. L., Gadelha, F. D. A., Kublik, N., Proctor, A., Reichelm, L., Weissinger, E., & Halden, R. U. (2015). Comparison of land, water, and energy requirements of lettuce grown using hydroponic vs. conventional agricultural methods. *International Journal of Environmental Research and Public Health*, 12(6), 6879–6891. <https://doi.org/10.3390/ijerph120606879>
- Benke, K., & Tomkins, B. (2017). Future food-production systems: vertical farming and controlled-environment agriculture. *Sustainability: Science, Practice and Policy*, 13(1), 13–26. <https://doi.org/10.1080/15487733.2017.1394054>
- Bren d'Amour, C., Reitsma, F., Baiocchi, G., Barthel, S., Güneralp, B., Erb, K. H., ... & Seto, K. C. (2017). Future urban land expansion and implications for global croplands. *Proceedings of the National Academy of Sciences*, 114(34), 8939-8944. DOI: <https://doi.org/10.1073/pnas.1606036114>
- Calvo, P., Nelson, L., & Kloepper, J. W. (2014). Agricultural uses of plant biostimulants. *Plant and Soil*, 383(1), 3–41. <https://doi.org/10.1007/s11104-014-2131-8>
- Despommier, D. (2013). Farming up the city: the rise of urban vertical farms. *Trends in Biotechnology*, 31(7), 388–389. <https://doi.org/10.1016/j.tibtech.2013.03.008>
- Dutko, P., Ver Ploeg, M., & Farrigan, T. (2012). Characteristics and influential factors of food deserts. USDA-ERS Economic Research Report, (140). DOI: <https://dx.doi.org/10.2139/ssrn.2114984>
- Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K. V., Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability*, 7(4), 4199–4224. <https://doi.org/10.3390/su7044199>
- Grunert, K. G., Sonntag, W. I., Glanz-Chanos, V., & Forum, S. (2018). Consumer interest in environmental impact, safety, health and animal welfare aspects of modern pig production: Results of a cross-national choice experiment. *Meat Science*, 137, 123–129. <https://doi.org/10.1016/j.meatsci.2017.11.022>

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- Hirschmann, R. (2021). Agriculture sector in Indonesia - statistics & facts. Statista. <https://www.statista.com/topics/5984/agriculture-in-indonesia/>
- Jürkenbeck, K., Heumann, A., & Spiller, A. (2019). Sustainability matters: Consumer acceptance of different vertical farming systems. *Sustainability*, 11(15), 4052. <https://doi.org/10.3390/su11154052>
- Kalantari, F., Tahir, O. M., Joni, R. A., & Fatemi, E. (2017). Opportunities and challenges in sustainability of vertical farming: A review. *Journal of Landscape Ecology*, 10(2), 35–60. <https://doi.org/10.1515/jlecol-2017-0016>
- Kozai, T., Niu, G., & Takagaki, M. (Eds.). (2019). *Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production*. Academic Press. <https://doi.org/10.1016/C2016-0-00398->
- Lakhiar, I. A., Gao, J., Syed, T. N., Chandio, F. A., & Buttar, N. A. (2018). Modern plant cultivation technologies in agriculture under controlled environment: a review on aeroponics. *Journal of Plant Interactions*, 13(1), 338-352. DOI: <https://doi.org/10.1080/17429145.2018.1472308>
- Lal, R. (2020). Home gardening and urban agriculture for advancing food and nutritional security in response to the COVID-19 pandemic. *Food Security*, 12(4), 871–876. <https://doi.org/10.1007/s12571-020-01058-3>
- Muthayya, S., Sugimoto, J. D., Montgomery, S., & Maberly, G. F. (2014). An overview of global rice production, supply, trade, and consumption. *Annals of the New York Academy of Sciences*, 1324(1), 7-14. DOI: <https://doi.org/10.1111/nyas.12540>
- Nguyen, N. T., McInturf, S. A., & Mendoza-Cózatl, D. G. (2016). Hydroponics: A versatile system to study nutrient allocation and plant responses to nutrient availability and exposure to toxic elements. *Journal of visualized experiments: JoVE*, (113), 54317. DOI: <https://doi.org/10.3791/54317>
- Nguyen, N. T., McInturf, S. A., & Mendoza-Cózatl, D. G. (2016). Hydroponics: A versatile
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... & Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, 372. <https://doi.org/10.1136/bmj.n71>
- Pinstrup-Andersen, P. (2018). Is it time to take vertical indoor farming seriously? *Global Food Security*, 17, 233–235. <https://doi.org/10.1016/j.gfs.2017.09.002>
- Resh, H. M. (2013). *Hydroponic food production: A definitive guidebook for the advanced home gardener and the commercial hydroponic grower*. CRC Press. <https://doi.org/10.1201/b13512>

-
- Sardare, M. D., & Admane, S. V. (2013). A review on plant without soil-hydroponics. *International Journal of Research in Engineering and Technology*, 2(3), 299–304. <https://doi.org/10.15623/ijret.2013.0203013>
- Shamshiri, R. R., Kalantari, F., Ting, K. C., Thorp, K. R., Hameed, I. A., Weltzien, C., ... & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. *International Journal of Agricultural and Biological Engineering*, 11(1), 1–22. <https://doi.org/10.25165/j.ijabe.20181101.3210>
- Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2018). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, 17(4), 364–371. <https://doi.org/10.5958/2455-7145.2018.00056.5>
- Specht, K., Siebert, R., Hartmann, I., Freisinger, U. B., Sawicka, M., Werner, A., ... & Dierich, A. (2014). Urban agriculture of the future: an overview of sustainability aspects of food production in and on buildings. *Agriculture and Human Values*, 31(1), 33–51. <https://doi.org/10.1007/s10460-013-9448-4>
- Sterne, J. A., Savović, J., Page, M. J., Elbers, R. G., Blencowe, N. S., Boutron, I., ... & Higgins, J. P. (2019). RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ*, 366. <https://doi.org/10.1136/bmj.l489>
- Touliatos, D., Dodd, I. C., & McAinsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food and Energy Security*, 5(3), 184–191. <https://doi.org/10.1002/fes3.83>
- Treftz, C., & Omaye, S. T. (2016). Comparison between hydroponic and soil systems for growing strawberries in a greenhouse. *International Journal of Agricultural Extension*, 4(1), 15–19.
- United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Urbanization Prospects: The 2018 Revision*. New York: United Nations. DOI: <https://doi.org/10.18356/b9e995fe-en>
- Wells, G. A., Shea, B., O'Connell, D. A., Peterson, J., Welch, V., Losos, M., & Tugwell, P. (2000). The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp
- Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science*, 341(6145), 508–513. DOI: <https://doi.org/10.1126/science.1239402>