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Microfinance, Vertical Farming, and Data-Driven Innovation in Bangladesh

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Abstract

This study examines the integration of microfinance with vertical farming initiatives in Bangladesh, aiming to address pressing challenges related to food security, urbanisation, and economic inequality. Vertical farming, a pioneering agricultural practice, maximises crop yields in limited spaces by employing techniques like hydroponics and aeroponics. It provides a sustainable solution for urban food production because it reduces dependency on traditional farming methods constrained by limited arable land and environmental challenges.

At the same time, microfinance empowers small-scale farmers and entrepreneurs by removing financial barriers such as the need for collateral and high interest rates. By offering accessible loans, microfinance institutions enable individuals to invest in vertical farming projects, so they can enhance productivity and improve their livelihoods. This research investigates the effectiveness of microfinance in supporting vertical farming, explores the operational dynamics of these initiatives, and evaluates their socio-economic impacts on farmers and communities.

In addition, the study highlights the critical role of data analysis and IT in improving the efficiency and scalability of vertical farming. By using IT solutions such as IoT-enabled sensors, farmers can monitor environmental conditions like temperature, humidity, and nutrient levels in real time. Data analysis helps optimise resource utilisation, such as water and energy, so that operational costs are minimised and crop quality is enhanced. These technologies also support decision-making by providing actionable insights that improve overall farming practices and product marketability.

To gather comprehensive data, the study adopts a mixed-methods approach, combining quantitative surveys and qualitative interviews. Key findings reveal that training in technical and IT skills is essential for the success of vertical farming projects. Microfinance institutions play a pivotal role not only in providing financial resources but also in facilitating access to equipment, technical support, and IT-driven monitoring systems. These elements are crucial for ensuring product quality, efficient resource management, and market readiness.

The study concludes that integrating microfinance with vertical farming, complemented by data analysis and IT, can significantly enhance food production, promote sustainable agricultural practices, and foster economic empowerment in urban and peri-urban areas. These findings offer valuable insights for policymakers, development practitioners, and agricultural entrepreneurs. They emphasise the importance of supportive policies, institutional collaborations, and investments in IT infrastructure to scale microfinance-supported vertical farming initiatives effectively.

Introduction:

Overview of Vertical Farming, Microfinance, and the Role of Data Analysis and IT: In recent years, the intersection of agriculture, finance, and technology has transformed the way food is produced and accessed. Vertical farming, an innovative approach to agriculture, has gained prominence as a solution to the challenges of food security in urban areas. By maximising crop yields in minimal space through techniques such as hydroponics and aeroponics, vertical farming not only optimises land use but also reduces reliance on traditional farming methods that are often constrained by limited arable land and environmental factors.

Simultaneously, microfinance has emerged as a critical tool for socio-economic development, empowering small-scale farmers and entrepreneurs by providing them with access to financial resources that would otherwise be unattainable. By offering tailored micro-loans without the need for collateral, microfinance institutions (MFIs) enable individuals from economically disadvantaged communities to invest in ventures like vertical farming, fostering self-reliance and resilience.

At the heart of this transformation is the integration of data analysis and IT, which enhances the efficiency of vertical farming operations. By leveraging data-driven insights, farmers can optimise resource utilisation, monitor environmental conditions in real time, and make informed decisions to maximise crop productivity. IT solutions, such as IoT-enabled sensors and predictive analytics, support precision farming by providing actionable data on water usage, nutrient levels, and light conditions. This synergy between vertical farming, microfinance, and technology holds immense potential for addressing food security challenges while promoting sustainable urban development and economic empowerment.

Rationale for the Study: The rationale for this study stems from the pressing global challenges of food security, urbanisation, and economic inequality. According to the United Nations, the global population is projected to reach 9.7 billion by 2050, with 68% of people expected to live in urban areas. This intensifies the demand for efficient agricultural systems that can supply fresh, nutritious produce despite limited arable land and logistical constraints.

Vertical farming addresses these challenges by enabling year-round crop production in controlled indoor environments, reducing dependency on seasonal variations and

geographical limitations. Its ability to optimise resource usage, such as minimising water consumption and cutting transportation costs, makes it an environmentally sustainable solution. However, implementing and scaling vertical farming projects often require financial resources and technical expertise, which are inaccessible to many small-scale farmers.

This is where microfinance plays a crucial role. By facilitating access to small-scale loans, microfinance enables individuals to overcome financial barriers and participate in innovative agricultural ventures. Furthermore, the inclusion of data analysis and IT in vertical farming significantly enhances its efficiency. For example, IT-driven monitoring systems allow farmers to track crop health and optimise growth conditions in real time. These technologies reduce waste, lower operational costs, and ensure consistent product quality, making vertical farming a viable and scalable solution for urban food security.

Objectives of the Study: The primary objective of this study is to critically examine the integration of microfinance with vertical farming, focusing on how data analysis and IT enhance its effectiveness. The specific objectives include:

1. **Assessing the Role of Microfinance in Supporting Vertical Farming**: Analysing how microfinance institutions provide not only financial resources but also technical support, including IT training, to aspiring and existing vertical farmers.
2. **Exploring the Impact of Data Analysis and IT on Vertical Farming**: Investigating the ways in which IT solutions optimise operations, improve productivity, and reduce resource consumption in vertical farming projects.
3. **Examining the Socio-economic Impact of Microfinance-supported Vertical Farming**: Evaluating how this integrated approach contributes to poverty alleviation, income generation, and community development.
4. **Identifying Policy Implications and Recommendations**: Offering insights into regulatory frameworks, institutional mechanisms, and technology investments needed to scale and sustain these initiatives.

Scope and Limitations: This study focuses on the integration of vertical farming and microfinance within urban and peri-urban contexts, particularly in developing regions where food security and urbanisation pressures are most acute. It examines the role of data analysis and IT in enhancing the viability of these projects. The scope includes quantitative and qualitative analyses derived from surveys, interviews, and case studies.
However, limitations such as potential biases in survey responses, challenges in accessing diverse data sources, and the contextual specificity of findings must be acknowledged. Despite these challenges, the study aims to provide actionable insights into the synergy between microfinance, vertical farming, and IT, offering valuable recommendations for stakeholders.

Significance of the Study: This study underscores the transformative potential of integrating microfinance, vertical farming, and IT to address global challenges. By demonstrating how data analysis and IT enhance the efficiency and scalability of vertical

farming, the study provides a roadmap for leveraging technology to promote sustainable agriculture and economic empowerment.

Moreover, the study contributes to the growing discourse on innovative agricultural practices and financial inclusion, highlighting how technology-driven solutions can address pressing issues such as climate change, urbanisation, and inequality. Policymakers, development practitioners, and entrepreneurs can use these insights to create an enabling environment for scaling such initiatives, ultimately fostering inclusive growth, resilience, and sustainability.

By exploring the role of IT and data-driven insights, this research bridges the gap between theoretical understanding and practical application, paving the way for impactful and scalable solutions to urban food security and economic inequality.

Literature Review

Vertical Farming of Lettuce Cultivars in Urban Bangladesh: Islam et al. (2021) conducted a study evaluating the growth, yield, and economic viability of lettuce cultivated vertically on unutilized building walls in Dhaka City. Their research recommended a growing media combination of 40% soil, 40% vermicompost, and 20% cocodust (V1P1) for superior plant growth, higher net economic return, and lower microbial contamination. This approach highlights the efficacy of organic amendments like vermicompost and cocodust in enhancing production. Despite the high initial installation costs of vertical farming systems, the long-term benefits justify the investment, especially in densely populated urban areas like Dhaka. Strategies to reduce costs through the use of locally available materials and seeking financial support are crucial for wider adoption.

Integrated Farming Systems: Prospects in Bangladesh: Al Mamun et al. (2011) discussed the prospects of Integrated Farming Systems (IFS) in Bangladesh, which integrate crops, livestock, trees, and sometimes aquaculture tailored to local agro-climatic conditions. IFS offers advantages such as increased food production, enhanced farm income through waste recycling, sustainable soil fertility, and diverse nutrient-rich foods. However, challenges include uneven adoption rates, feed shortages, labor bottlenecks, and high start-up costs. Despite these challenges, IFS proves effective in promoting sustainability and resilience while diversifying income streams for smallholder farmers in Bangladesh.

Vertically Integrated Contract Poultry Farming in Bangladesh: Begum (2005) assessed vertically integrated contract poultry farming in Bangladesh, highlighting its economic impact and challenges. The study revealed that small farms dominate in terms of numbers but contribute less to total farm area compared to medium and large farms. Contract farming adoption among small farms is driven by factors like lack of capital, risk reduction, and access to marketing facilities. Financially, contractors cover a significant portion of production costs and offer insurance against bird mortality, thereby reducing farmers' price and production risks. The study underscores the importance of contract farming in

providing a guaranteed market, technical training, and higher net returns, thereby generating employment and stabilizing income across sectors.

State of the Art of Urban Smart Vertical Farming Automation Systems: Saad et al. (2021) reviewed the current status and challenges of urban smart vertical farming automation systems. They identified significant issues such as high initial costs, yield variability, energy dependence, and environmental impacts in traditional vertical farming. However, the integration of IoT, AI, and sensor technologies in urban smart vertical farming shows promise in mitigating these challenges through real-time data collection and analysis. Recommendations include prioritizing R&D investment, enhancing technological integration for resource optimization, and scaling up through modular designs and partnerships to achieve sustainable urban agriculture.

Current Status and Future Challenges in Implementing Vertical Farming Systems: Van Delden et al. (2021) provided insights into the current status and future challenges in implementing and upscaling vertical farming systems. They highlighted technological advancements and environmental benefits of vertical farming, such as reduced pesticide use and lower water consumption. Challenges include initial cost barriers and the need for policy support to facilitate widespread adoption. The study emphasizes the potential of vertical farming systems in enhancing food security and sustainability, provided that challenges related to scalability and economic viability are adequately addressed.

Rooftop Gardening in Urban Bangladesh: Challenges and Opportunities: Sheel et al. (2019) explored rooftop gardening in Khulna City of Bangladesh, focusing on plant cultivation preferences, operational practices, pest management, and environmental impacts. The study revealed widespread cultivation of flowers and vegetables among respondents, with common pest issues addressed through manual and organic control measures. Challenges such as excessive heat and inadequate nourishment were identified, highlighting the need for improved training programs, financial support, and infrastructure to promote sustainable rooftop gardening practices.

Financial Analysis Framework for Vertical Farming Systems: Moghimi et al. (2020) presented a framework for financial analysis of vertical farming systems, discussing the economic feasibility and challenges associated with vertical farming. They highlighted higher operational costs compared to traditional agriculture but identified opportunities in crop selection and technological advancements to improve profitability. Strategies include optimizing supply chains, enhancing consumer education, exploring financing options, and fostering collaboration with research institutions to ensure economic competitiveness and sustainability.

Economic Estimation System for Vertical Farms: Shao et al. (2016) developed an economic estimation system for vertical farms, incorporating factors like initial investment, labor, energy, and environmental impact. Their model aims to maximize expected profit while minimizing production and price risks, offering a structured approach to assess economic viability compared to traditional agriculture. The study underscores the potential

of vertical farming systems in achieving sustainable, environmentally friendly, and financially competitive food production, contingent upon refined sub-models and empirical validation.

Economic Feasibility Analysis of Vertical Farming: Global Perspectives: Moghimi (2021) conducted a global economic feasibility analysis of vertical farming across different locations and farm types, highlighting profitability variations and influencing factors. The study identified crop profitability and technological advancements as key determinants of economic viability. Challenges include high initial costs and variability in ROI across different farm types, necessitating supportive policies and market-oriented strategies to enhance competitiveness and sustainability.

Overview of Vertical Farming on High-Rise Residential Balconies: Sengodan (2022) provided an overview of vertical farming on high-rise residential balconies, focusing on solar radiation availability, climate suitability, and economic viability in Malaysian urban environments. The study emphasized innovative approaches such as using air-conditioning condensate for hydroponic water sources and highlighted the economic potential of vertical farming despite challenges related to solar radiation and climate conditions.

Research Gap:

1. Effectiveness of Microfinance Models in Vertical Farming: Current literature lacks detailed empirical studies on the effectiveness of different microfinance models specifically tailored for vertical farming. Understanding which types of microfinance institutions (e.g., NGOs, banks, cooperatives) and loan structures (e.g., repayment terms, interest rates) are most conducive to supporting vertical farming ventures is crucial. Comparative studies across regions and socioeconomic contexts could provide valuable insights into optimal microfinance strategies that enhance access to resources and ensure sustainable farming practices.

2. Impact Assessment of Microfinance-Enabled Vertical Farming: There is a need for comprehensive impact assessments that evaluate the socio-economic outcomes of microfinance-enabled vertical farming initiatives. Studies should assess indicators such as income generation, food security, livelihood improvement, and empowerment of marginalized communities. Longitudinal studies that track the economic trajectories of farmers post-loan repayment can shed light on the sustainability and long-term benefits of integrating microfinance with vertical farming.

3. Technological Integration and Innovation: Research focusing on the integration of technological innovations (e.g., IoT, AI) within microfinance-supported vertical farming systems is limited. Exploring how advanced technologies can optimize resource use, improve crop yields, and reduce operational costs is essential for scaling up vertical farming initiatives. Studies could also investigate the role of digital platforms in facilitating loan disbursement, training delivery, and market access for farmers.

4. Risk Management and Resilience Building: Understanding the risks associated with microfinance-supported vertical farming ventures and developing strategies to mitigate these risks is critical. Research should explore risk factors such as climate variability, market fluctuations, and operational challenges specific to urban agriculture. Insights into risk management practices adopted by microfinance institutions and their impact on farmer resilience can inform policy interventions and best practices.

5. Policy and Institutional Support: There is a gap in research examining the role of supportive policies and institutional frameworks in fostering microfinance-enabled vertical farming ecosystems. Comparative analyses of policy environments across different countries or regions could highlight regulatory barriers and facilitators affecting the scalability and sustainability of urban farming initiatives. Studies should also explore institutional partnerships that enhance access to markets, technical assistance, and extension services for vertical farming practitioners.

6. Gender and Social Inclusion: Research on gender dynamics and social inclusion within microfinance-supported vertical farming initiatives is sparse. Exploring how gender norms, access to resources, and decision-making influence the outcomes of female farmers involved in vertical farming could uncover opportunities to promote gender equity and social empowerment. Similarly, studies focusing on marginalized groups (e.g., ethnic minorities, rural migrants) can highlight barriers to inclusion and recommend targeted interventions to promote equitable access to microfinance and agricultural resources.

Conceptual Framework For Vertical Farming Process With Microfinance Support

Overview: This conceptual framework illustrates the integration of microfinance and vertical farming to enable economically disadvantaged individuals to start and sustain farming operations. The process involves several stages, starting from obtaining a loan to repaying it after earning profits from the farming business. Each step is crucial for ensuring the success and sustainability of the vertical farming initiative.

Fig 1: Conceptual Framework

Steps in the Framework:

1) **Microfinance Company**: The journey begins with a microfinance company that provides the necessary financial support to individuals who wish to start vertical farming.
2) **Training for Loan**: Before receiving the loan, potential farmers undergo training to ensure they have the necessary skills and knowledge to effectively use the funds and equipment for vertical farming.
3) **Setup by Microfinance Company**: Once the loan is approved, the microfinance company sets up all the required equipment to start the vertical farming process. This setup includes infrastructure, tools, and initial resources necessary for farming.
4) **Start Farming Process**: With the equipment in place, the farming process begins. This step involves planting, maintaining, and growing crops using vertical farming techniques.
5) **Monitoring by Microfinance Company**: Throughout the farming process, the microfinance company monitors the operations to ensure everything is progressing smoothly and to provide any needed support.
6) **Evaluate Product Quality**: As the crops grow and reach maturity, the microfinance company evaluates the quality of the products to ensure they meet market standards.
7) **Collecting Product**: Once the products are ready, they are collected from the farming site. This step involves harvesting and preparing the produce for sale.
8) **Bringing the Product to Market**: The collected products are then brought to microfinance-authorized or owned grocery or retail shops (e.g., Shopno) where they are made available for purchase by customers.
9) **Selling the Product**: The products are sold directly to customers, generating revenue for the farmers.
10) **Earning Money**: The sales revenue allows the farmers to earn money, providing them with financial stability and the ability to sustain their farming operations.
11) **Earning Profit**: Beyond covering their costs, the farmers aim to earn a profit, which further incentivizes them to continue and possibly expand their farming business.
12) **Repaying the Loan**: Finally, with the profits earned, the farmers repay the loan to the microfinance company. This repayment completes the financial cycle and ensures the sustainability of the microfinance support system, allowing it to assist more individuals in the future.

Methodology: This study employs a mixed-methods approach to investigate the integration of microfinance support with vertical farming, focusing on its impact and effectiveness. Quantitative data were gathered through structured surveys administered to 35 respondents involved in microfinance-supported vertical farming initiatives. Key variables such as training adequacy, initiation of farming processes, product quality evaluation, and market distribution were assessed using descriptive statistics to analyse proportions and percentages. Qualitative insights were obtained through interviews with stakeholders including farmers, microfinance representatives, and agricultural experts to provide

contextual understanding and nuanced perspectives on the operational dynamics and challenges. The data analysis involved thematic coding of qualitative data and statistical interpretation of quantitative findings to uncover patterns, correlations, and implications for policy and practice. This mixed-methods approach ensures comprehensive exploration of the multifaceted aspects of microfinance-supported vertical farming, contributing to both theoretical understanding and practical recommendations for sustainable agricultural development.

Data Analysis:

Table 1: Proportion Enough Training on Vertical farming

Training	Respondent (n=35)	Percentage
Yes	28	83%
No	07	17%

Table 1 shows, highest 83% of the total respondent said they have enough training on vertical farming from relevant way. According to the data analysis, it can be said that training is very important in this sector. Essentially, No one can succeed in a vertical farming project without proper training. Because vertical farming is a very scientific process where a lot of technical training has to be implemented.

Microfinance companies set up all equipment of Vertical Farming

Various technical assistance in direct farming:

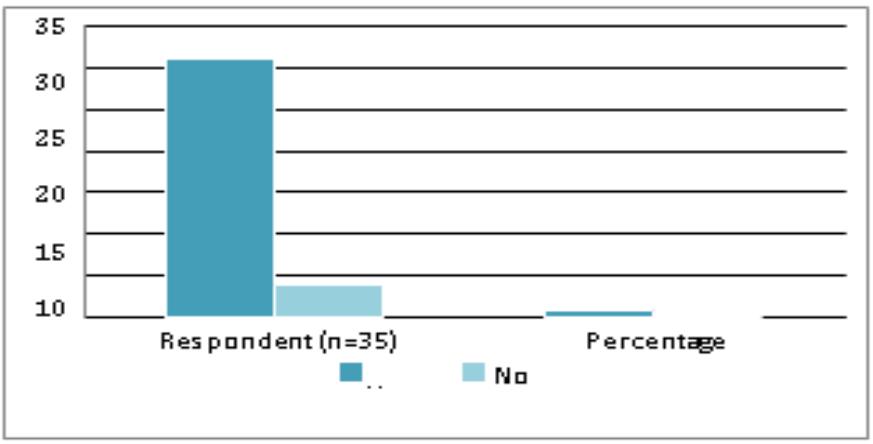
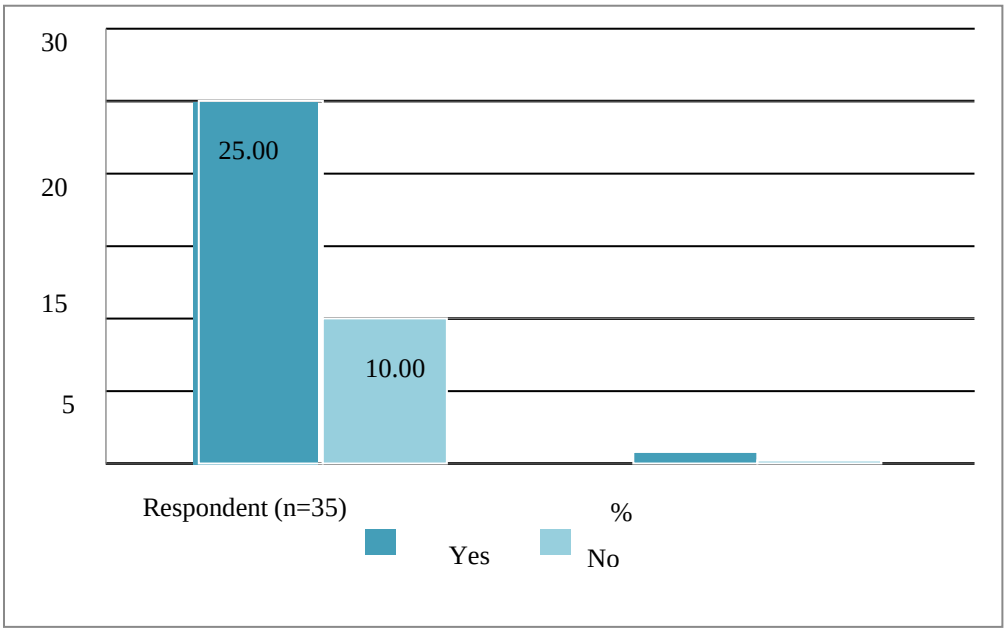


Fig 2: Various technical assistance in direct farming

The graph review shows that microfinance companies are setting up all the equipment required for farming after verifying the training. The highest number of respondents said yes to this issue. As we have said in the analysis of the previous table, training is one of the most important aspects of this sector. Microfinance companies do not provide loans until training is verified.

Table 2: Proportion of start farming process

Training	Respondent (n=35)	Percentage
Yes	30	90%
No	05	10%



According to the above table (Table 2) analysis, the highest number of respondents said that microfinance companies are starting the farming process on time. Along with investment, financial companies also agree with that. The above graph analysis shows that a maximum of 80% of respondents say that microfinance companies control the vertical farming process through proper monitoring.

The implementation of IT systems enables microfinance companies to verify training through digital records and automate the evaluation process. Data analytics further assist in identifying optimal farming schedules and monitoring the initial stages of vertical farming.

Table 3 : Proportion of evaluate product quality

Product Quality	Respondent (n=35)	Percentage
Yes	28	83%
No	07	17%

Through the use of data analysis tools, microfinance companies can evaluate product quality more accurately. IT systems allow for real-time tracking of crop conditions, identifying inconsistencies, and ensuring market-ready produce.

Since the company has to take responsibility for the marketing of the manufactured goods as well, in that case a lot of awareness is adopted about the quality of the manufactured goods. If the product quality is marketable, the stability of the company will increase in the market and the project will be successful. The above table shows, highest 83% of the total respondent said microfinance companies evaluated the product quality.

Microfinance companies Collecting all products: Data analysis and IT play a pivotal role in streamlining the product collection process. Digital inventory management systems and predictive analytics ensure timely collection and reduce post-harvest losses.

Graph analysis shows that a maximum of 95% of respondents say that microfinance companies are collecting products. Microfinance companies operate entirely in the area of product procurement. Data analysis is also playing a leading role in product marketing.

Table 4: Own Super shop (Showpno Moodel)

Product Quality	Respondent (n=35)	Percentage
Yes	32	97%
No	03	03%

The table 4 reveals that a maximum of 97% of respondents say that the products produced and collected by microfinance companies are brought to their authorized selling points or to their own supermarkets for direct selling.

Result Discussion: By analyzing the results obtained on the subject of vertical farming and microfinancing in this sector, it can be said that training is very important in this sector. Essentially, no one can succeed in a vertical farming project without proper training. Because vertical farming is a very scientific process where a lot of technical training has to be implemented.

Vertical farming is a very new farming system in our country, so microfinance companies set up the necessary equipment for vertical farming. Analysis shows that the microfinance companies are setting up all the equipment required for farming after verifying the training. The highest number of respondents said yes to this issue. As we have said in the analysis of the previous table, training is one of the most important aspects of this sector. Microfinance companies do not provide loans until training is verified.

As mentioned earlier, the vertical farming process is a completely new technology. Here, those who do the microfinance behind the farms basically start the farming process by assembling all the necessary things. According to the analysis, the highest number of respondents said that microfinance companies are starting the farming process on time. Along with investment, financial companies also agree to provide various technical assistance in direct farming.

Analysis shows that a maximum of 80% of respondents say that microfinance companies control the vertical farming process through proper monitoring.

It can be seen in the data analysis, the highest 83% of the total respondent said microfinance companies evaluated the product quality. Since the company has to take responsibility for the marketing of the manufactured goods as well, in that case a lot of awareness is adopted about the quality of the manufactured goods. If the product quality is marketable, the stability of the company will increase in the market and the project will be successful.

Graph analysis shows that a maximum of 95% of respondents say that microfinance companies are collecting products. Microfinance companies operate entirely in the area of product procurement. Data analysis is also playing a leading role in product marketing.
It can be seen that a maximum of 97% of respondents say that the products produced and collected by microfinance companies are brought to their authorized selling points or to their own supermarkets for direct selling.

There is no doubt that development is now visible everywhere in Bangladesh. It can play an important role in building a healthy, crime-free, terror-free and unemployment-free society. A country can develop depending on agriculture. Applying this thought many unemployed youths can become self-reliant and take the country and nation to a new height. I think there is no potential loss in this assumption. Therefore, the government can benefit economically by using this idea and avoid important financial problems like market supervision. Microfinance can also transform modern agriculture. It is only a matter of time before the breakthrough changes. So it can't really be green banking?

Benefits of vertical Farming: IT solutions, such as IoT-enabled sensors and data analytics platforms, make vertical farming smarter and more sustainable. These technologies provide farmers with actionable insights, allowing for precise control over water usage, light, and nutrients.

One of the most important objectives of vertical agriculture is to achieve maximum production using minimum land. It provides suitable conditions for the growth of plants in almost all conditions. Therefore, there is no need to wait for a specific season to harvest.
It provides a plan for meeting future food demand that provides a continuously improved quality rich crop. This type of cultivation allows the crop to grow all year round which is not dependent on weather and seasons. It uses significantly less water or saves up to 95%. In this way more organic crops can be cultivated so that there is less exposure to chemicals and diseases.

It can greatly reduce the use of agricultural land and wastage of food and bring maximum freshness to the city. Vertical farming reduces transportation costs to buyers; Limits carbon dioxide emissions; It has less negative impact on climate and brings agriculture back to the daily life of urban people.

In addition, food from vertical farms is usually sold locally resulting in reduced emissions caused by transportation and time to reach the table from the farm. This simplifies the supply of fresh or pure produce without any delay or reduces the process of marketing from the farm to a few days to just a few hours. By 2050, about 7% of the world's population is expected to live in urban areas and the growing population will increase food demand; Therefore, efficient use of vertical cultivation may play an important role in preparation for such a challenge. Indoor vertical farming can significantly reduce the occupational hazards associated with conventional farming. Farmers do not face the problem of using heavy farming equipment, deadly diseases like malaria, toxic chemicals etc.; There is no harm to animals and plants on the ground; Conservation of natural resources can overcome various environmental problems and is also conducive to making biodiversity humane and environmentally friendly.

Disadvantages

1. **Huge costs:** Vertical farming is quite costly and some use urban settings where the real estate prices are high, thus, its maintenance costs are even higher as compared to traditional farming.
2. **High Energy Consumption:** During the growing season, the sun shines on a vertical surface at an extreme angle such that much less light is available to crops than when they are planted on flat land.

Although vertical farming requires significant energy and investment, data-driven IT solutions can optimise resource usage and reduce operational costs, making the system more economically viable.

Conclusion: 'Green' is a rare commodity in our cities. But the dark green color gives peace to the eyes. Vertical Farming can be a blessing for these rough-and-tumble cities. As well as greening our porches or roofs, it can play a unique role in our food security. In the world of future urbanization, when arable land is very scarce compared to the population, methods like vertical cultivation will become very necessary. The integration of IT and data analytics into vertical farming ensures a data-driven approach to food production, enabling sustainable urban agriculture that meets future food demands efficiently.

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