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A novel framework of vegetable supply chain digitalization to improve the business performance

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Abstract

Perishability causes financial loss to the business of fresh vegetables which are consumed after a short period of harvesting. Moreover, inadequate supply chain (SC) systems contribute to vegetable wastage having issues with storage, distribution, and transportation. Recent research affirms that the integration of digital technologies has a positive impact on the supply chain and logistics. Therefore, in this study, digitalization of the vegetable supply chain (VSC) is focused to mitigate the losses and to enhance the business of vegetable products in Bangladesh. A comprehensive method developed based on in-depth surveys to identify the reasons for waste in the VSC. The survey data were collected to explore the factors of wastages to analyze the significant contributors correlating to the perishability. Finally, the adoption of digital solutions is assessed through the expectation of the stakeholders in the vegetable retail chain. The proposed framework provides actionable insights to enhance vegetable business.

Keywords: Vegetable waste, framework, factors, digital solution, supply chain challenges

1. Introduction

Vegetable farming, one of the important agricultural practices, significantly influences the economy and food security in Bangladesh. However, several challenges persist in vegetable supply especially the post-harvest losses due to the perishability. Moreover, inadequate supply management contributes to the wastage. Fig. 1 (a) shows the picture of the wholesale market at Kawran Bazar, Dhaka, Bangladesh [1], where vegetables are brought from all over the country. The flow of freshly produced vegetables in the supply chain (SC) is shown in Fig. 1 (b) [2]. Rapid decay of perishable items leads to a reduction in quality and nutrient content in the post-harvest stages. This causes huge losses to farmers, and other stakeholders involved in vegetable production and distribution business due to inappropriate storage methods, poor transportation infrastructure, and inefficient market systems [3].

Even with improved agricultural technology, lack of digitalization of the SC contributes to gaps in traceability, monitoring, and decision-making in real time; hence, a lack of transparency [4] [5] [6]. Recent literature highlights that digitalization of the SC can unlock promising opportunities for improving operational efficiency, traceability, and reduction of losses [7] [8]. The factors affecting the perishability of vegetables within the SC are temperature, humidity, and inefficiencies in transport. The most common adverse effects of high temperatures are increased respiration rates, resulting in quick deterioration, while inappropriate humidity induces mold growth or dehydration, both of which significantly reduce the shelf life of produce [9]. Transportation accentuates these issues through long transit times and variable handling, since the vegetable is subjected to a wide range of environmental conditions which can hasten spoilage [10]. However, digitization presents a strategic solution by enabling real-time monitoring of the produce along the SC [11]. Once these factors are addressed through digitization, vegetable supply chain (VSC) can largely reduce product losses and thereby maintain quality for perishable vegetables to improve profitability and sustainability.



Fig. 1. (a) and fruits market, Dhaka, Bangladesh [1], (b) vegetable flow in the supply chain [2]

This research spotlights the shortcomings of the VSC of Bangladesh by investigating the causes of post-harvest losses through in-depth surveys of retailers and distributors. It identifies critical factors for the wastages and, in the same breath, also proposes solutions through digital interventions as listed in the below objectives:

- To analyze the survey data to identify the significant factors related to waste in VSC.
- To develop a framework for the adoption of digitalization in vegetable business.

2. Methodology

The study followed an in-depth survey considering consumer behavior, market dynamics, storage facilities, and transit conditions to determine the impacts on vegetable wastage. These subjective factors were used to prepare a survey questionnaire focused on gathering information by following quantitative methods to explore the circumstances that various stakeholders in the VSC face. There are several constraints to the commercialization of vegetables in different urban and pre-urban areas which include perishability, vegetable wastage, labor cost, unavailable storage facilities leading to the losses. Lack of postharvest handling practices and storage facilities leads to a large amount of damage for raw markets both inside and outside of Dhaka city. Again, technology integration in VSC ensures higher efficiency and lesser damage along with wastage. This is essential for modifying transportation, logistics, storage development, and improving awareness among sellers and buyers. Therefore, urban areas were mostly concentrated in this study to identify the major hurdles and causative factors in VSC wastage. All the survey data were collected from authentic vendors, retailers, wholesalers, street vendors, and supermarkets, through face-to-face investigation. The most advantageous fact was collecting the information by field visit that ensured data accuracy and minimized response bias, sampling issues, and accessibility issues. Thus, the proposed methodology consists of a bottom-up approach of data collection related to an empirical study of identifying the factors need to consider for digitalization of VSC in Bangladesh.

3. Survey Results and Analysis

A total of 92 responses were collected from various areas of Dhaka city with the respondent's occupation shown in Fig. 2 (a). The street vendors and e-commerce consist of the largest and smallest portion, respectively. The business experience in Fig. 2(b) shows the wholesalers operating in the 11-15 year category is the most and retailers are second most having a 6-10 year experience. Freshness of the vegetables was reported as the most important priority of the supermarket customers followed by the low price and the on-time delivery by the retailer and e-commerce, respectively as shown in Fig. 3.

Different responses obtained for the quality and freshness check of vegetables are illustrated in Fig. 4(a), where most of the respondents used experience-based and word-of-mouth evaluation followed by a visual inspection. Fig. 4(b) represents the comparison of the wastage levels for both leafy and vegetable categories. Maximum wastages of 21-30% in leafy and non-leafy vegetables reported from wholesalers followed by 11-20% reported by retailers and street vendors, while the later shows high wastage in vegetables. On the other hand, e-commerce and supermarkets show lesser wastages in all categories probably due to better storage or higher efficiency.

Fig. 5 shows responses to the challenges considering wastage during delivery, transportation issues, packaging, and storage. Wholesalers considered most on the vegetable wastages due to transportation/distribution. Street vendors consider the highest difficulty as poor road conditions followed by high transportation costs. Wholesalers use jute sacks while retailers use nylon sacks as the main type of packaging. Supermarket chains and e-commerce platforms, particularly regarding transport and storage, have better SCs. Again, street vendors reported inadequate storage problems and thus, needs specific ameliorative interventions.

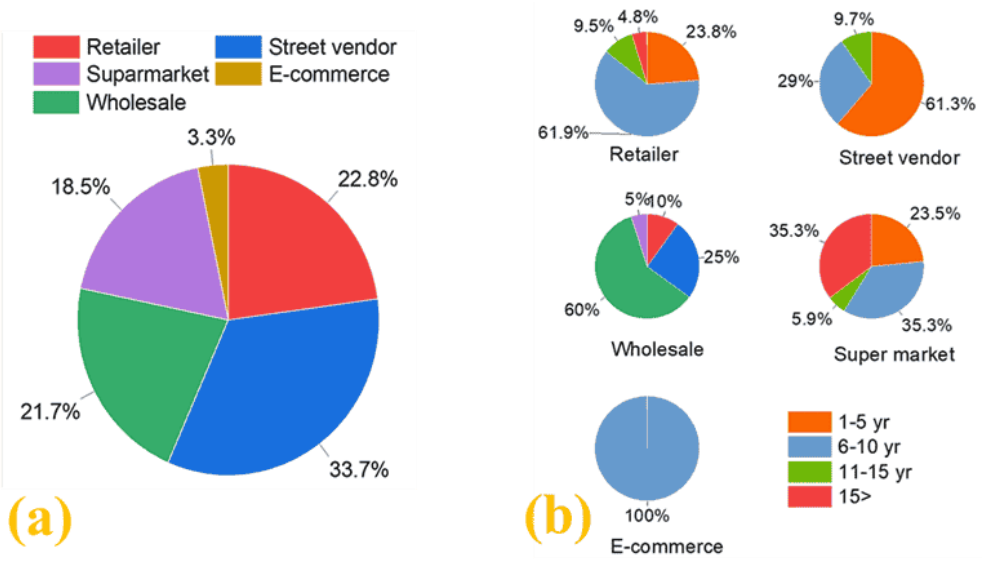


Fig. 2. (a) Percentage distribution of respondents (b) respondents' business experience.

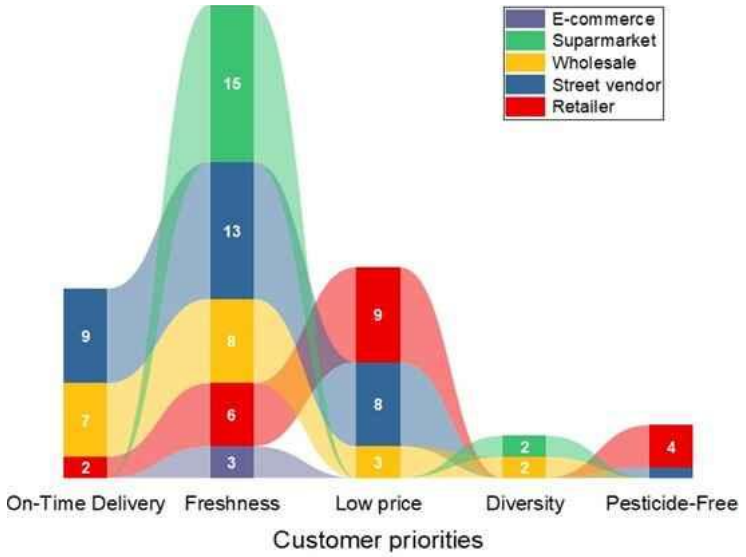


Fig. 3. Customer priorities across different sales channels

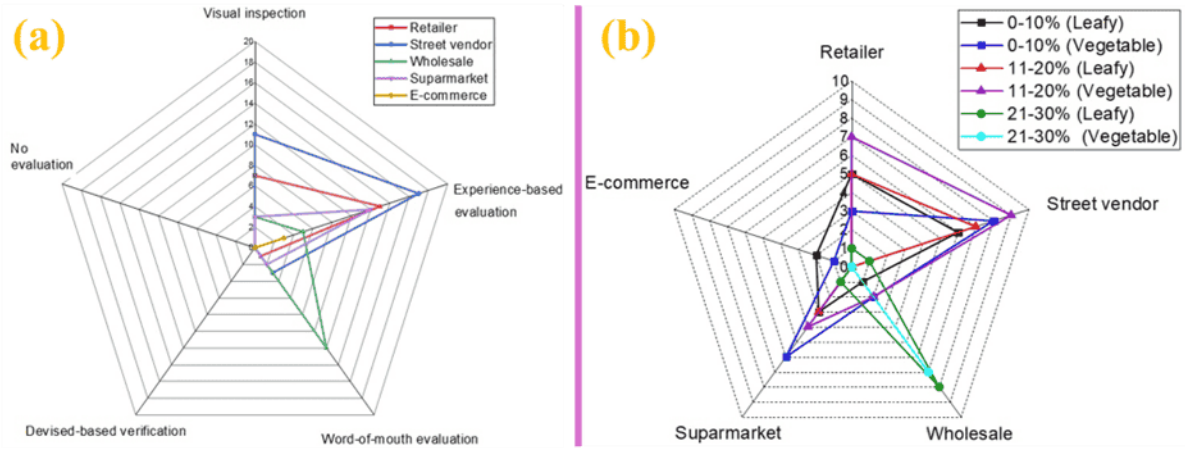


Fig. 4. Response on the (a) quality and freshness checking (b) wastage of leafy and vegetables

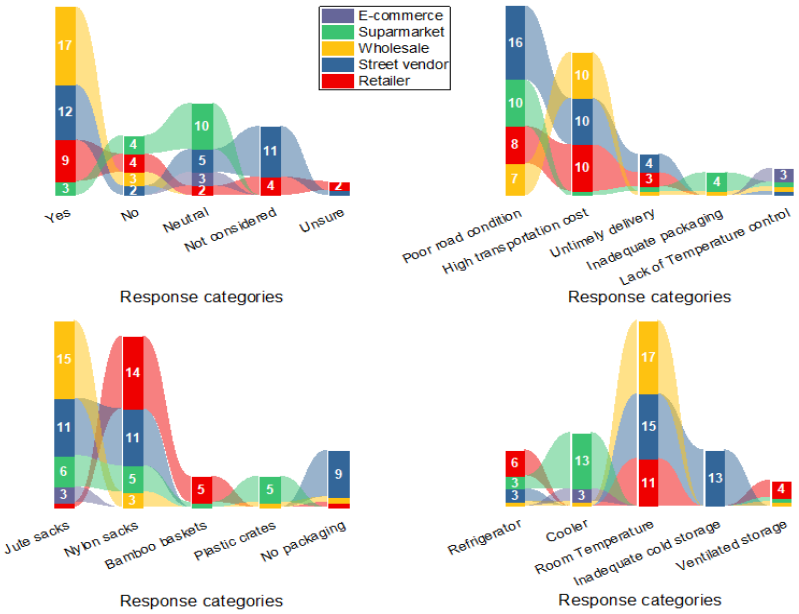


Fig. 5. Respondent's views on the wastage during transport/delivery, transportation challenges, packaging used and storage methods

Adoption of digital medium response is shown in Fig. 6, where most respondents use phone calls followed by SMS and internet for customer order receiving. E-commerce platforms are very willing to adopt digital technologies for the internet as digital media (Fig. 6a), tracking benefit (Fig. 6b), employing devices for quality control (Fig. 6c), and digital storage management (Fig. 6d) appropriately. Supermarkets are next to e-commerce for willing to adopt the digital tools. Wholesalers and retailers are on average willing to participate in these areas. In contrast, street vendors have the least readiness, which indicates that support and encouragement are needed.

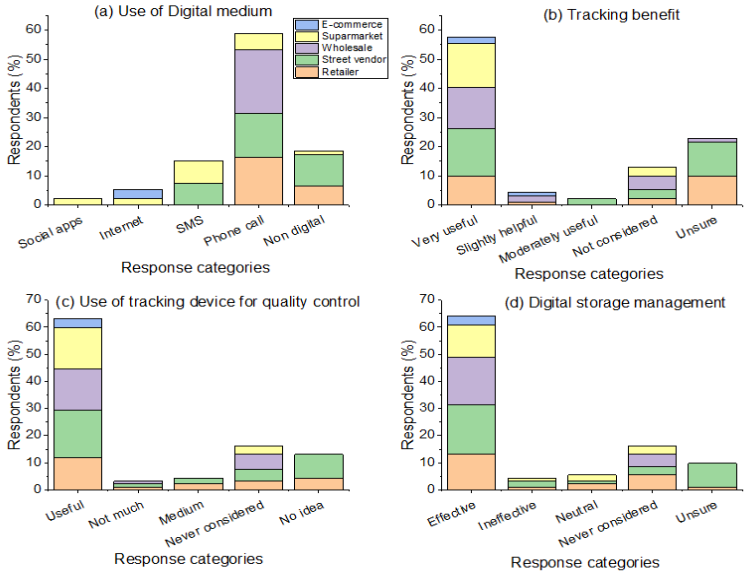


Fig. 6. Survey responses on the adoption of digital medium as (a) digital media use, (b) tracking benefit, (c) tracking devices use for quality control, and (d) digital storage management

The level of support for digital technology adoption is shown in Fig. 7, where the supermarket and street vending prioritize training support followed by financial support for street vending and wholesaling. The preferences of wholesalers and retailers to receive technical support are at a moderate level to manage digital systems. E-commerce platforms, already advanced in the sphere of digital adoptions, demonstrate the least need for support from outsiders. A small share of the total, mainly street vendors who have never thought about digital adoptions, while retailers and supermarkets remained unsure about their needs.

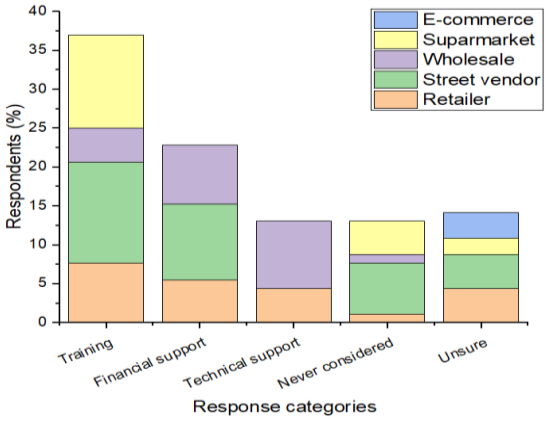


Fig. 7. The level of support required for digital technology.

4. A novel framework to adopt digitalization in vegetable supply chain

The findings of this study demonstrate unique preferences and challenges across different segments of the VSC in Bangladesh. Understanding this uniqueness is crucial for implementing targeted improvements catering to the specific needs of each customer group and address critical issues in the SC. For instance, the supermarket customers prioritize fresh and pesticide-free vegetables, emphasizing the importance of quality and ensuring produce is at its peak when purchased. On the other hand, e-commerce prioritizes on-time delivery, underscoring the need for reliable logistics and efficient transportation to meet consumer expectations. Wholesalers and retailers prioritize competitive pricing of vegetables and leafy greens, reflecting their focus on cost-efficiency and affordability to remain competitive in the market.

The study identifies that the wholesale level experiences the highest vegetable wastage, indicating inefficiencies that need urgent attention to reduce losses throughout the SC. Poor road conditions and high transportation costs emerge as significant challenges, impacting both the quality of vegetables during transit and the overall profitability of stakeholders. Packaging practices, such as the prevalent use of jute and nylon sacks, play a crucial role in maintaining product integrity. However, the survey notes room temperature storage as a prevalent practice, highlighting potential improvements needed to extend shelf life and reduce spoilage.

Digital innovations offer promising solutions to enhance efficiency and address these challenges. The adoption of digital storage solutions and tracking devices for quality control can significantly improve inventory management and ensure that vegetables maintain optimal freshness throughout the SC. Implementing digital media strategies tailored for e-commerce and supermarket channels can enhance visibility and consumer trust, thereby boosting sales and customer satisfaction. The study emphasizes that adopting digitalization tools (i.e., IoT sensors and devices), and platforms (i.e., mobile, internet, apps and dashboards) can provide predictive analytics both strategically and operationally to empower stakeholders to address inefficiencies and enhance the resilience of VSC. This digital transformation is crucial for reducing post-harvest losses, improving operational efficiency, and bolstering market competitiveness in Bangladesh's agricultural sector.

Hence, a novel framework in this study is proposed (Fig. 8) that provides actionable insights for researchers, entrepreneurs, and policymakers seeking to enhance perishable VSC efficiency. By focusing on digital solutions, stakeholders can implement strategies to mitigate losses, improve transparency, and ensure sustainable growth in the vegetable sector. Practical applications include the adoption of IoT sensors and devices for real-time monitoring, blockchain for enhanced traceability, and predictive analytics for informed decision-making. These technologies should address current challenges. It also should help sustainably position Bangladesh's agricultural sector in a globalized market.

4.1 Limitations of study and Future Directions

While the current study provides valuable insights, the findings have limitations in terms of geographic locations as data collections were mostly focused on retailing to acquire the raw information. There are several avenues for future research to expand the understanding of digitalization in Bangladesh's VSC. First, future studies aim to broaden the geographic scope by capturing data from diverse regions of Bangladesh to account for regional variations in agricultural practices, infrastructure, and market dynamics. Second, future research will explore cost-effective solutions that make digital technologies accessible to all stakeholders, particularly small-scale street vendors and retailers. Finally, further study is required to assess the enduring impacts of digitalization on economic, environmental, and social sustainability within the VSC. Studies should evaluate how digital technologies influence profitability, resource efficiency, food security, and resilience to climate change.

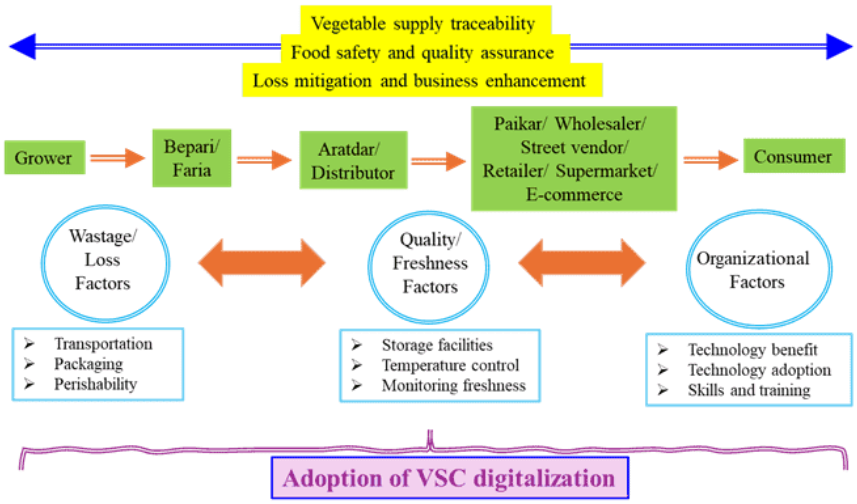


Fig. 8. A novel framework for VSC digitalization adoption

5. Conclusion

The digitalization of the VSC represents a transformative step towards addressing the challenges faced by Bangladesh's agricultural sector. By aligning strategies with specific customer preferences—freshness for supermarkets, punctuality for e-commerce, and affordability for retailers—stakeholders can enhance market competitiveness and operational efficiency. Embracing digital technologies holds the key to overcoming critical challenges such as wastage at the wholesale level, poor road conditions, and high transportation costs. By leveraging technologies such as blockchain, IoT, and predictive analytics, stakeholders can overcome inefficiencies and enhance the resilience of the SC. By prioritizing inclusive strategies and ongoing research efforts, the country can unlock the full potential of digital technologies to sustainably elevate its agricultural sector. To fully harness the potential of digitalization, it is crucial to prioritize inclusive strategies and ongoing research initiatives. Implementing targeted interventions to enhance packaging practices and integrate digital innovations is essential for ensuring long-term viability in the VSC and business competitiveness. However, implementation costs, infrastructure limitations, and technological illiteracy among stakeholders may hinder the widespread adoption of vegetable VSC digitalization.

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