

OPTIMIZING THE SUPPLY CHAIN OF TOMATOES IN NIGERIA: CHALLENGES, SUSTAINABILITY, AND COLD CHAIN SOLUTIONS

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Abstract

Tomatoes are generally, a staple in Nigerian diets and a crucial agricultural product, both in terms of consumption and a source of income, and Nigeria is one of the largest producers of tomatoes in Africa, producing approximately 2.3 million metric tons annually. However, post-harvest losses account for nearly 50% of total tomato production, impacting food security and economic sustainability. This is mainly due to the inefficiencies in the supply chain leading to significant post-harvest losses. The lack of a robust cold chain infrastructure exacerbates these losses, for example, Nigeria's cold storage facilities are insufficient, with less than 1% of perishable goods transported under refrigerated conditions, making it difficult for farmers and distributors to maintain quality and reduce waste. Market and price volatility, where seasonal fluctuations in supply lead to unstable prices, with tomato prices rising by up to 300% during the off-season. Poor handling, lack of storage, and inadequate transportation infrastructure contribute to significant losses, estimated at 750,000 to 1.2 million metric tons annually. Furthermore, out of 160 countries, Nigeria is ranked as the 131st in the World Bank Logistics Performance Index, this clearly indicates the severe inefficiencies in the transportation and logistics matrix of the country. This paper therefore, explores the challenges in Nigeria's tomato supply chain and presents sustainable cold chain solutions to enhance efficiency, minimize losses, and improve profitability for stakeholders. The paper explores the challenges in the Nigerian tomato supply chain and the role of sustainable cold chain solutions in reducing post-harvest losses. Using qualitative and quantitative data from industry reports, government policies, and case studies, the paper highlights innovative strategies, such as solar-powered refrigeration and blockchain traceability, to enhance efficiency and sustainability. Findings reveal systemic challenges such as weather dependence, limited access to technology, poor road networks, and consumer behavior that discourage preservation methods. It concludes that cold chain innovations can significantly improve food security, reduce waste, and boost profitability across Nigeria's tomato value chain. The study advocates for integrated, sustainable interventions including infrastructure investment, policy support, and capacity-building initiatives. These strategies when implemented, can significantly reduce tomato wastage, improve food security, and enhance economic growth in the agricultural sector.

Keyword: Supply Chain of Tomatoes, Sustainability, and Cold Chain Solutions.

1. Introduction

Tomatoes are generally, a staple in Nigerian diets and a crucial agricultural product, both in terms of consumption and a source of income and Nigeria is one of the largest producers of the product

in the African continent, with an annual production capacity of over two million metric tons. However, post-harvest losses account for nearly 50% of total tomato production, impacting food security and economic sustainability. This is mainly due to the inefficiencies in the supply chain leading to significant post-harvest losses. The lack of a robust cold chain infrastructure exacerbates these losses, for example, Nigeria's cold storage facilities are insufficient, with less than 1% of perishable goods transported under refrigerated conditions, making it difficult for farmers and distributors to maintain quality and reduce waste. Market and price volatility, where seasonal fluctuations in supply lead to unstable prices, with tomato prices rising by up to 300% during the off-season. Poor handling, lack of storage, and inadequate transportation infrastructure contribute to significant losses, estimated at 750,000 to 1.2 million metric tons annually. Furthermore, Nigeria ranks 131 in the World Bank Logistics Performance Index, this indicates severe inefficiencies and inadequacy in the transportation, storage and the logistics supply chain. The significance of this study cannot be underestimated as it provides considerable contribution in the tomatoes supply change processes. The paper critically examined the challenges in Nigeria's tomato supply chain on a fourfold face; namely, from the production stage to the transportation, then the market stage and the consumer stage. The challenges were analyzed as it affects the Nigerian tomato supply chain. The paper further explored the role of sustainable cold chain solutions in reducing the post-harvest losses. More specifically, the paper evaluated the pursuit of environmentally and carbon-reduced solutions of sustainable cold chains to support tomatoes as a perishable good. Cold chains in perishable products refers to a temperature-controlled supply chain that ensures perishable goods maintain their quality and safety from production to consumption. It involves adopting a unique system of storing and transporting temperature-sensitive products that is maintained within a specific allowable temperature range (Zego, 2024). It involves a series of coordinated events using refrigerated storage and transportation. The key aspects of a cold chain that the paper examines include, first, temperature control, that is maintaining consistent temperatures throughout the supply chain. Second, monitoring, which involves the tracking of the temperatures to ensure they remain within acceptable ranges. Third, the issue of storage. This involves the application of refrigerated warehouses and facilities that ensures the maintenance of the health nature of the product. Finally, transportation, that includes the employment of refrigerated trucks, ships, and other means. Therefore, the paper emphasizes the crucial role of temperature-controlled logistics in protecting tomatoes as a sensitive perishable good.

2. Literature Review

2.1 Tomato Production in Nigeria

Several studies highlight the dominance of smallholder farmers in Nigeria's tomato production landscape (Adewumi & Adebayo, 2021). These farmers often lack access to quality seeds, irrigation systems, and post-harvest storage, contributing to spoilage and limited scalability. The study of Ugonna, Jolaoso, and Onwualu (2015) on the appraisal of the value chain in the production and processing of tomato in Nigeria, provided a good example. The study employed semi-structured informal interviews particularly with key value chain actors such as producers, intermediate traders, retailers and input suppliers. Their findings indicated that although there exist various varieties of tomatoes in Nigeria, it is only a few that are suitable for industrial processing. This means that only a few of the varieties provides the good quantity and quality of the tomatoes that is needed in the processing industry. They also found that the use of inadequate supply of good quality seeds, poor disease and pest management, inadequate storage facilities, and poor processing facilities account for the poor yield of the paste in the processing industries. They

recommended policy shift to encourage small and medium enterprises (SMEs) as well as Industries along the value chain; improved input supplies; organization of farmers into cooperatives so as to increase the possibilities and chances of funding. They also encourage the famers to establish groups in form of clusters for both processors and research that will see to the development of better and improved seed varieties. The study further recommended the adjustments of the strategy in marketing so as a guaranteed minimum price will be established for fresh tomatoes, this will extend to also developed a better strategy for the processing and storage of the products.

The study of Oso, (2020), on arthropod pests and how it inflicts economic damage on tomato fruit borer, thrips and leaf miners is also a good contribution on the quality of varieties. The paper highlighted the general introduction of tomato, its botany, nutritional benefits, tomato value chain in Nigeria, Nigerian government interventions towards its sustainability with particular focus on research cocktails at combating the problems of the pests on the product and identifying the best probable and critical solutions to these harmful pests.

Oke, Lawanson, and Muhammed (2019) presented a Supply-Side Analysis of the Market for Tomato in Bauchi State. The data employed were purposively obtained from farmers, wholesalers and retailers from agricultural areas in 7 Local Government Areas of Bauchi State. These include Darazo, Bauchi, Toro, Alkaleri, Shira, Kari, and Ganjuwa. The findings from the paper shows that farm characteristics majorly affect supply of tomatoes while handling costs and cooperative membership are mainly responsible for loss of tomatoes across the marketing chain. Therefore, the membership of the cooperative does not in any way, play significant role in improving the situations of the farmers, even the middlemen do not much benefit with regards to increased profitability. Furthermore, they found farm characteristics and socioeconomic alignment to be the key main factors that affects tomatoes' profitability.

Sarley, Mahmud, Idris, Osunkiyesi, Dibosa-Osador, Okebukola, Wiwa (2017). Examined the transformation of vaccines in the supply chains in Nigeria. The paper found that vaccine supply chain transformation project in Nigeria achieved impressive results, but the sustainability of these results is uncertain due to challenges such as GAVI graduation, economic downturn, and decentralized health funding. The transformation strategy included data-driven decision making, comprehensive cold chain management, and supply chain redesign at both the federal and state levels. Onwude *et al.* (2023), examined the factors that account for the loss of income by tomatoes famers to include, Poor Road infrastructure, access to data and expertise, and lack of a continuous cold chain. They found that over 40% of fresh tomato produce in Nigeria is been lost after harvest, this invariably affects the income of the smallholder farmer's income to the tune of more than 30% loss. A major bottleneck is the lack of a continuous cold chain, with less than 10% of fresh produce passing through a cold chain despite long travel distances. Poor road infrastructure, with only 31% of the road network paved, contributes significantly to post-harvest losses. with less than 10% of fresh produce passing through a cold chain despite long travel distances. with only 31% of the road network paved, contributes significantly to post-harvest losses. Takeshima (2023), also advocated for a shift of agricultural policy by the authorities to enhance and overcome the problem of sessional famers.

2.2 Post-Harvest Losses in Agricultural Supply Chains

Post-harvest losses refer to the degradation in quantity or quality of food after harvesting. According to the FAO (2020), nearly 50% of perishable produce in Sub-Saharan Africa is lost due to inefficient storage, transport, and handling. Globally there are documented studies that asserts the occurrence of substantial losses of fresh perishable products, including tomatoes, which

necessitates the dear need for an effective cold chain logistics operation (Zego, Junaida & Mohamad, 2024). Cold chain logistics operations over the years have encountered challenges which has impeded their reliability, efficiency, and possible market growth. In the Nigeria for example, the study of Zego *et al.* (2024), documented a number of challenges that are been faced by the tomato value chain in Nigeria. They documented up to 50% annual losses in the tomato supply chain which is mainly attributable to poor storage, transportation, and processing. This was further anchored by the study of Ugonna *et al.* (2015). Through purposive sampling, semi-structured interviews, focus group discussions, and reflexive thematic analysis, Zego *et al.* (2024), identified the challenges faced by cold chain logistics stakeholders in the tomato value chain in Nigeria to include inadequate stakeholder collaboration problems, cold chain logistics, production challenges, and supply chain risks. They also enumerated the themes that reflected challenges to include stakeholder's poor collaborations and visibility challenge, financial challenges, supply chain risk, socio-cultural challenges, government and policy challenges and the theme on production and farming challenges.

Idah, Ajisegiri, Yisa (2007), administered structured questionnaire specifically to the handlers and transporters of the tomato products, in about ten major markets across Nigeria, using the personal interviews and investigative survey research approach. They also took the measurements of the dimensions and weights of some handling devices in addition to the loss assessment. The results from the study shows that the current system is bedeviled with a lot of problems. One major fact is that, most of the transporters do not actually own the vehicles they use, this makes it difficult in getting the desired vehicles for the transportation, which automatically causes delay, and subsequent decay of the tomato products. It is estimated that an average of 13.89% of the fresh tomato delivered to the market was damaged (Idah, Ajisegiri, Yisa 2007). Apart from the transportation problem, even the packaging of the products and the containers used were adjured to be unsuitable to the transport system. Adepoju (2014) examined the effects of post-harvest losses on the welfare of 107 tomato farmers in Ogbomosho selected through a multi-stage sampling procedure. Using descriptive statistics, Ordinary Least Square (OLS), gross margin analysis, and regression model the papers shows that tomatoes famers incurred a 95.5% post-harvest loss. The total value of post-harvest losses and the household size were found to significantly affect the per-capita income and hence welfare of the tomato farmers negatively. The paper recommended training of famers adequately on post-harvest crop handling techniques.

Arah (2015), in an attempt to account for the post-harvest challenges facing the production of tomato, the study identifies on-farm problems and on the other hand the off-farm problems. On the earlier, On-farm, the challenges include improper harvesting containers, improper harvesting stages and or periods, poor farm sanitation, excessive field heat, and improper packaging materials. While on the latter, Off-farm, the challenges include lack of processing factories, lack of access or bad roads leading to production fields, lack of market information, inappropriate transportation system, lack of effective storage facilities and reliable markets. The paper recommended the use of low-cost intermediate technology intervention to help reduce the post-harvest constraints.

Aishwarya Mohan (2023), studied the postharvest losses among the Indian tomato famers, exploring different technologies to address the postharvest losses and challenges in implementing those technologies. They use the case study approach to collect relevant data for the research. The paper found that for postharvest losses across the stages of reduced there's the need to tackle storage and long-distance transport. The study advocated for collaboration among the supply chain partners and temperature-controlled storage facilities as the possible best solutions in addressing the challenges.

Gatahi (2020), identified pest and diseases, high cost of inputs, postharvest losses and lean markets as the major challenges facing tomato production in Nigeria. The study highly recommended the use organic tomato in the production process as an emerging market niche. To them, there is increased consumer awareness on health-related practices and the environmental conservation requirements that is practiced globally. Thus, farmers have been making strides towards compliance to organic and other sustainable standards. Kitinoja, Odeyemi, Dubey, Musanase, Gill (2019) This study was conducted to identify and quantify the main causes and sources of losses in the tomato postharvest chain from harvest to the consumer at the retail market, in one of the harvest sessions, the study used the assessment methodology of modified commodity system on the tomato and found that although there is increase in harvest with higher losses. The study also observed that the results is the same across the three countries used in the research Nigeria, India and Rwanda. In Nigeria, the losses range between 10 to 40% of the tomato produced, this is from the farm where it is produced to the consumer at the retail market, and mainly due to poor handling and non-availability of the needed storage facilities. While in Rwanda, it reaches 50 to 60%. Factors contributing to these huge losses were poor-quality seeds, rough handling of the products and the use of inappropriate packaging materials. In India, the loses were mild at 1 to 18%, the main cause was attributed to pest and disease attack and low-price realization that is been experienced during glut season.

2.3 Cold Chain Technologies in Developing Economies

Cold chains involve temperature-controlled environments for storing and transporting perishables. Recent innovations, such as solar-powered cold rooms and mobile cold boxes, are gaining traction in Sub-Saharan Africa (Bolarinwa et al., 2022). These technologies significantly reduce spoilage but require targeted investment and policy support to scale.

Zego, Junaida & Mohamad (2024), investigated the nexus on how the relationship between schedules planning and cold chain logistics vehicles routing effects the safe distribution of fresh tomato in Nigeria. They employed the use of a focus group discussion and semi-structured interview for data collection analyzed the data using thematic analysis. They found that insecurity challenges, infrastructure limitations, regulatory challenges, absence of well-defined supermarket channels, transportation challenges, weather challenges and market demand uncertainties seriously effects vehicle routing and scheduling planning which negatively affects fresh tomato distribution in Nigeria.

Anka Datta, Swapan C. Sarkar, Sonal Choudhary, Bryan Shaughnessy, Tiju Thomas (2023) Proper temperature and humidity management are crucial for maintaining tomato quality and sustainability in the supply chain. The paper fund that Tomatoes have a short shelf life due to post-harvest physiological, physical, and chemical changes. - Proper temperature and humidity management is crucial for maintaining the quality of tomatoes during storage. The tomato product is generally essential commodity in its both its fresh stage. It has many health benefits, including preventing cancer and cardiovascular diseases. The shelf life of tomatoes is relatively short due to post-harvest physiological, physical, and chemical changes that occur during storage.

2.4 Blockchain in Agricultural Supply Chains

Blockchain technology offers transparency and traceability in food value chains. In regions like India and Kenya, pilot blockchain platforms have improved consumer trust and reduced fraud in agri-business (Mukherjee & Jain, 2020). However, its application in Nigeria remains nascent.

2. Methodology

This paper adopts a mixed-methods approach, combining both qualitative and quantitative research techniques to provide a holistic understanding of the challenges within Nigeria's tomato supply chain and evaluate the potential of sustainable cold chain solutions. The methodology is structured around four key stages of the supply chain: production, transportation, market, and consumer stages. This paper therefore, explores the challenges in Nigeria's tomato supply chain on a fourfold face; namely, from the production stage to the transportation, then the market stage and the consumer stage. The challenges were analyzed as it affects the Nigerian tomato supply chain, we further explored the role of sustainable cold chain solutions in reducing post-harvest losses. Post-harvest challenges are challenges faced by producers, processors, distributors, retailers as well as exporters in handling the produce after it has been harvested until it gets to the final consumer. The paper also advanced strategies to enhance efficiency, minimize losses, and improve profitability for stakeholders. The key aspects of a cold chain that the paper examines include, maintaining consistent temperatures throughout the supply chain, by tracking to ensure they remain within acceptable ranges. Then using refrigerated warehouses and facilities in getting the products to the final destination, with this, the paper emphasizes the crucial role of temperature-controlled logistics in protecting tomatoes as a sensitive perishable good.

3.1 Data Collection Techniques

- a. Secondary Data Industry Reports: Data was obtained from agricultural and supply chain reports published by the Nigerian Ministry of Agriculture, the National Bureau of Statistics (NBS), and the Food and Agriculture Organization (FAO). Government Policies: Reviewed policy documents on agriculture, food preservation, infrastructure development, and sustainable practices. Case Studies: Studied documented interventions and pilot projects, including the use of solar-powered cold rooms and blockchain-based tracking systems in parts of Nigeria and other comparable regions.
- b. Primary Data. Key Informant Interviews (KIIs): Conducted semi-structured interviews with farmers, distributors, market vendors, cold chain operators, and consumers. Surveys: Distributed structured questionnaires to 150 stakeholders across the supply chain in Makarfi, Kaduna, Kudan, and Birnin Yaro, focusing on post-harvest loss, transportation bottlenecks, and technology adoption. Focus Group Discussions (FGDs): Organized FGDs involving different stakeholder groups to gather in-depth qualitative insights on systemic challenges and opportunities.
- c. Sampling Strategy. The research uses purposive sampling technique to select participants with direct involvement in the tomato supply chain. Ensure representation across all stages of the supply chain, including production, transportation, market, and consumer levels.

3.2 Data Analysis

- a. Qualitative Analysis. Thematic Analysis: Transcripts from interviews and FGDs were coded and analyzed to identify recurring themes, challenges, and perceptions around supply chain inefficiencies. SWOT Analysis was also conducted to assess the strengths, weaknesses, opportunities, and threats of current post-harvest handling practices and cold chain technologies.
- b. Quantitative Analysis. Descriptive Statistics: Used to summarize survey data, including frequency distributions of post-harvest loss percentages, adoption rates of cold chain solutions, and income levels. Comparative Analysis: Evaluated the performance of traditional supply chain processes versus innovative interventions like solar refrigeration and blockchain traceability. Loss Estimation Models: Estimated economic losses due to spoilage at each stage of the supply chain using data on production volumes, transport distances, and spoilage rates.

3.3 Case Studies.

Identified case studies were Examined, more specifically on case studies of successful cold chain solutions (e.g., solar-powered refrigeration) implemented within and outside the study area. We also analyzed blockchain traceability implementations in tomato supply chains to assess feasibility and potential benefits.

3.4 Validation and Triangulation

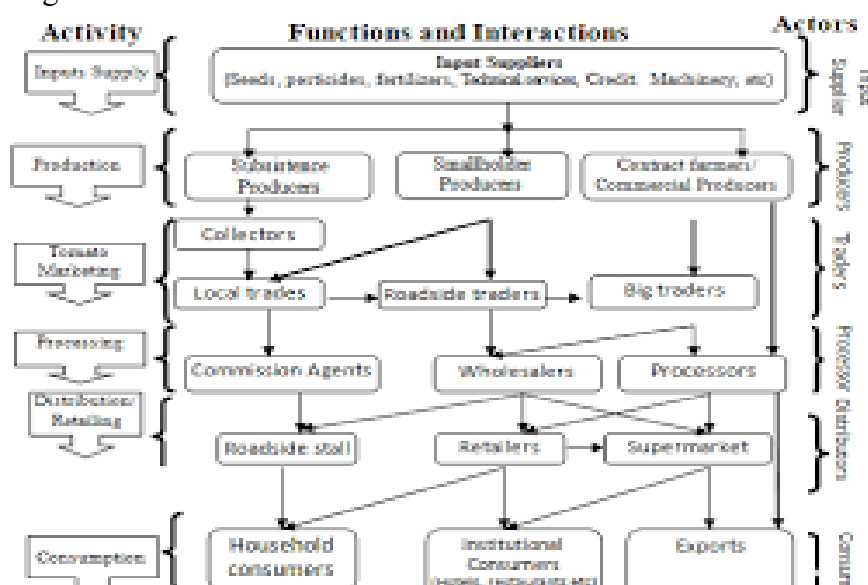
To ensure reliability and validity: Data from multiple sources (government, industry, and direct stakeholders) were cross-verified. Findings from qualitative and quantitative sources were triangulated to confirm key insights.

3.5 Evaluation Metrics.

Assess the challenges and solutions using metrics such as: Post-harvest loss percentages across the supply chain. Cost-effectiveness and profitability improvements for stakeholders. Adoption rates of innovative solutions like cold chain technologies or blockchain systems.

3. Findings and Analysis

The findings from both qualitative and quantitative data reveal critical bottlenecks across all four stages of the tomato supply chain in Nigeria. The results are organized into key thematic areas aligned with the structure of the supply chain: production, transportation, market, and consumer stages.



The diagram above shows a flowchart that visually represents the various challenges and issues encountered at different stages of the tomato value chain. It's designed to give a clear, quick overview of where problems occur, from the farm to the consumer, and also touches on the efforts to introduce solutions.

4.1 Production Stage: This section focuses on the problems farmers face *before* and *during* the harvest of tomatoes. **Limited Access to Inputs & Technology:** Many farmers (over 65%) still rely on traditional farming methods. This means they might not have access to modern equipment (minimal mechanization), high-quality seeds (like high-yield tomato varieties), or proper fertilizers and pesticides. This leads to lower yields, less efficient farming, and makes them less competitive. **Poor Storage Infrastructure:** A significant majority of farmers (70%) do not have proper storage facilities on their farms. This results in immediate spoilage of tomatoes right after harvest, as they

have nowhere safe to keep them before transport. Weather Dependence: Farmers are highly vulnerable to unpredictable weather patterns. The unanticipated rainfall or heatwaves cause significant crop losses (65% of farmers reported this), highlighting the impact of climate variability.

The SWOT analysis indicates that weaknesses include lack of farmer training, poor access to preservation technology. While the opportunities include Introduction of solar-powered cold rooms and extension services.

4.2 Transportation Stage: This section describes the challenges in moving tomatoes from the farms to markets or other destinations. Inadequate Transport Facilities: More than half of the distributors (55%) use basic, open vehicles like vans or lorries. This exposes the delicate tomatoes to direct sunlight, dust, and physical damage during transit, accelerating spoilage. High Spoilage Rates: A large percentage of harvested tomatoes (35-45%) are lost during transportation itself. This is due to poor handling practices (e.g., stacking without proper cushioning) and the complete lack of cold storage in transport vehicles. Poor Road Networks: The condition of roads, particularly between rural farming areas and urban markets, is very poor. Bad roads increase travel time significantly, leading to more bumps and jostling, which further damages the tomatoes and accelerates their deterioration.

The report of the quantitative analysis on loss estimation indicates that using reported transport distances and spoilage rates, average losses were calculated at approximately \$100 per ton annually.

4.3 Market Stage: This section covers the problems encountered once tomatoes arrive at the market for sale. Limited Cold Storage at Markets: Very few urban market vendors (only 15%) have access to cold storage facilities, and rural markets have none at all. Without refrigeration, tomatoes quickly spoil, forcing vendors to sell them off quickly or lose their stock. Market Gluts and Price Volatility: During peak harvest seasons, there's often an oversupply of tomatoes in the market. This excess supply drives prices down sharply, leading to financial losses for farmers and traders, and more unsold, spoiled produce. Lack of Aggregation Centers: There aren't enough organized collection points where farmers can bring their produce together. This leads to inefficient and scattered supply chains, making it harder to manage quantity and quality for larger buyers.

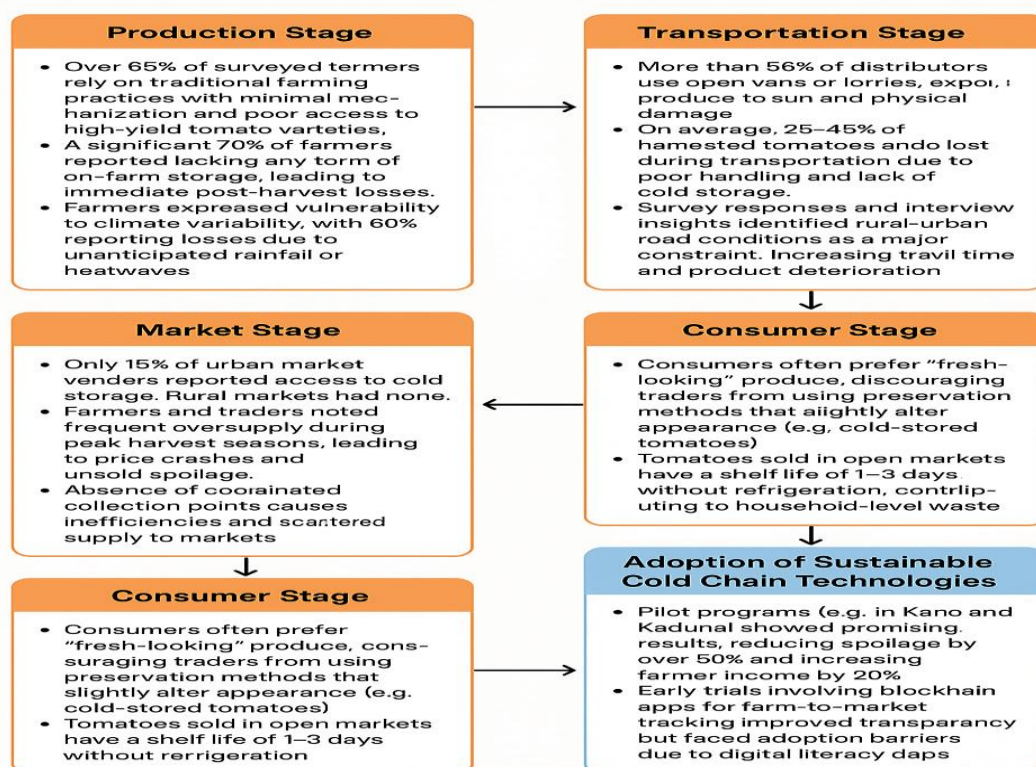
The Descriptive Statistics shows that 60% of market vendors reported weekly losses exceeding 25% of inventory, and less than 20% had access to cold rooms or proper storage. The Thematic analysis shows that vendors expressed strong interest in cooperatively owned cold rooms, but cited high energy costs as a barrier.

4.4 Consumer Stage: This section highlights issues at the end of the chain, concerning consumer preferences and household waste. Consumer Awareness & Behavior: Consumers often prefer tomatoes that look "fresh" and pristine. This discourages traders from using preservation methods (like cold storage) that might slightly alter the appearance of the tomato, even if it extends shelf life. This preference contributes to more waste of less "perfect-looking" but still good produce. Short Shelf Life: Tomatoes sold in open markets, without refrigeration, have a very short usable life. They typically last only 1-3 days, contributing significantly to food waste at the household level.

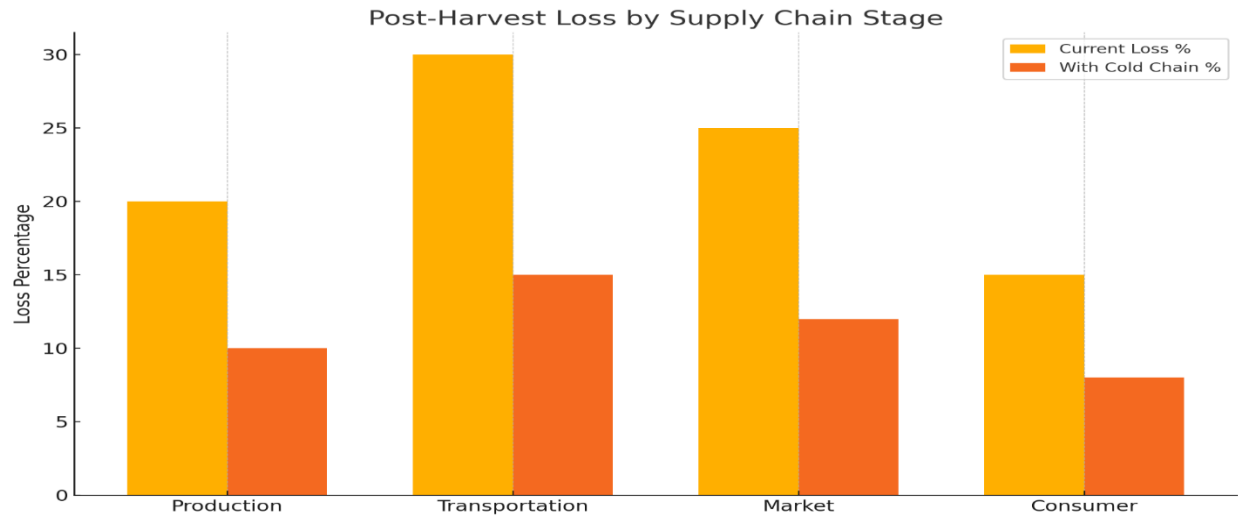
The Survey Findings indicates that more than 70% of respondents would be willing to pay more for longer-lasting tomatoes. However, only about 20% were aware of cold storage or traceability benefits.

4.5 Adoption of Sustainable Cold Chain Technologies: This final section shifts to potential solutions and the challenges in implementing them. **Solar-Powered Cold Rooms:** Pilot projects in specific areas (Kano, Kaduna) have demonstrated the effectiveness of using solar energy for refrigeration. These initiatives have shown promising results, significantly reducing spoilage (over 50%) and increasing farmers' incomes (by 20%). This highlights a viable technological solution. **Blockchain for Traceability:** Early trials of blockchain applications for tracking tomatoes from farm to market were conducted. While they improved transparency in the supply chain, widespread adoption faced barriers due to gaps in digital literacy among farmers and traders. **Perception and Willingness to Pay:** A good number of traders expressed interest in cold chain services. However, the high cost (affordability) and lack of sufficient awareness about the long-term benefits remain significant hurdles to wider adoption of these technologies.

In essence, the diagram illustrates a complex web of interconnected problems that lead to substantial losses in the tomato value chain. While technological solutions exist (like solar cold rooms), their successful adoption requires addressing issues of cost, awareness, infrastructure, and digital literacy. Summarize below as:

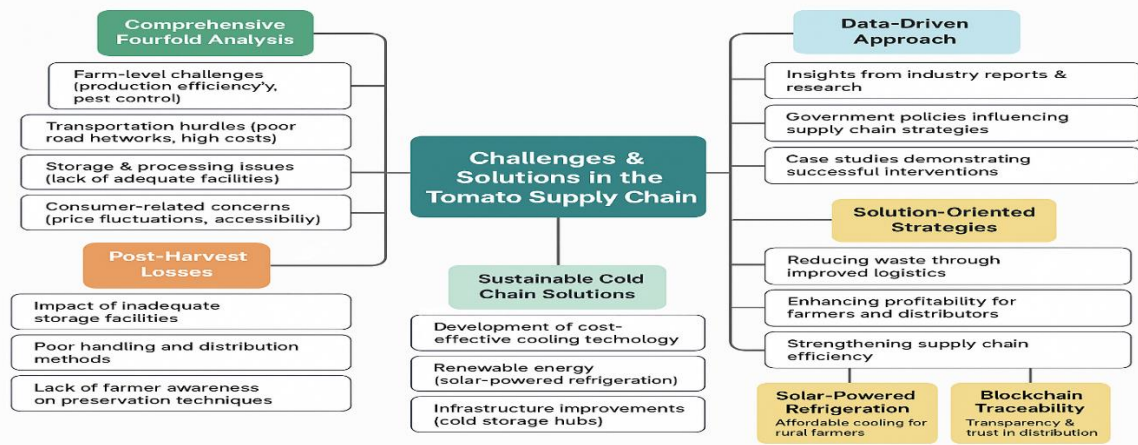


Validation and Triangulation: Cross-referencing of the data from the surveys ensured consistency. Case studies and government reports confirmed trends and bottlenecks. Also, Data convergence around key challenges (transport loss, poor storage) strengthens reliability of the findings.



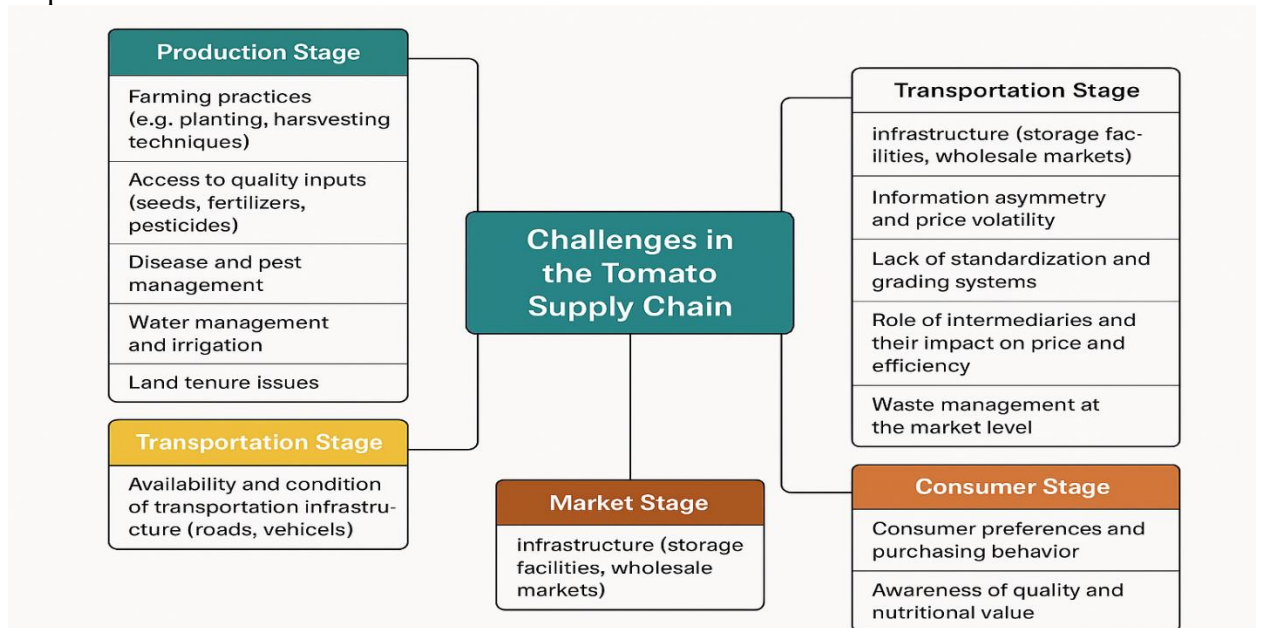
4.6 Key Strengths and Focus Areas:

Comprehensive Fourfold Analysis: The paper's strength lies in its structured approach, examining the challenges across the entire tomato supply chain from the farm to the consumer. This holistic view is crucial for understanding the interconnected nature of the problems. **Focus on Post-Harvest Losses:** By specifically addressing post-harvest challenges, the paper targets a significant area of concern in agricultural supply chains, particularly in developing economies where infrastructure and technology limitations often lead to substantial waste. **Emphasis on Sustainable Cold Chain Solutions:** The exploration of sustainable cold chain solutions is highly relevant. It acknowledges the need for environmentally friendly and economically viable methods to preserve the quality and extend the shelf life of tomatoes. **Data-Driven Approach:** The use of both qualitative and quantitative data from diverse sources (industry reports, government policies, case studies) lends credibility and depth to the analysis. **Solution-Oriented:** The paper goes beyond simply identifying problems by advancing concrete strategies to enhance efficiency, minimize losses, and improve profitability for all stakeholders involved. **Highlighting Innovative Strategies:** The inclusion of innovative strategies like solar-powered refrigeration and blockchain traceability demonstrates a forward-thinking approach and offers practical pathways for improvement.



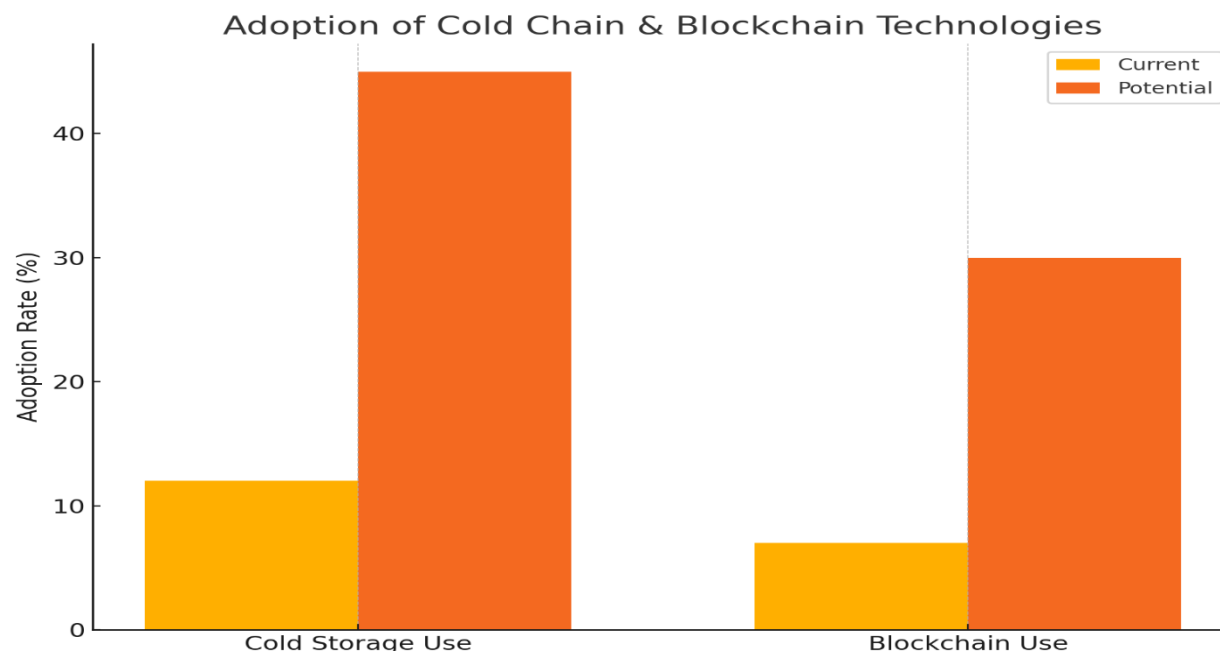
4.7 Likely Areas of Exploration within Each Stage:

- **Production Stage:** Farming practices (e.g., planting, harvesting techniques). Access to quality inputs (seeds, fertilizers, pesticides). Disease and pest management. Water management and irrigation. Availability of labor and its skills.
- **Transportation Stage:** Availability and condition of transportation infrastructure (roads, vehicles). Logistics and coordination challenges. Lack of refrigerated transport and its impact on spoilage. Transportation costs and their effect on profitability. Multiple handling and its contribution to damage.
- **Market Stage:** infrastructure (storage facilities, wholesale markets). Information asymmetry and price volatility. Lack of standardization and grading systems. Role of intermediaries and their impact on price and efficiency. Waste management at the market level
- **Consumer Stage:** Consumer preferences and purchasing behavior. Awareness of quality and nutritional value. Impact of spoilage on affordability and access. Potential for value-added processing at the consumer or retail level
- A detailed diagram representing the stages of the tomato supply chain, covering Production, Transportation, Market, and Consumer aspects. Hope this visualization helps!



4.8 The Role of Sustainable Cold Chain Solutions:

The paper likely explores how cold chain technologies, particularly sustainable options like solar-powered refrigeration, can mitigate post-harvest losses by: Maintaining optimal temperatures to slow down spoilage and microbial growth. Extending the shelf life of tomatoes, allowing for wider distribution and reduced waste.¹ Preserving the quality, nutritional value, and marketability of the produce. Potentially creating new opportunities for value addition and market access.



4.9 Discussion

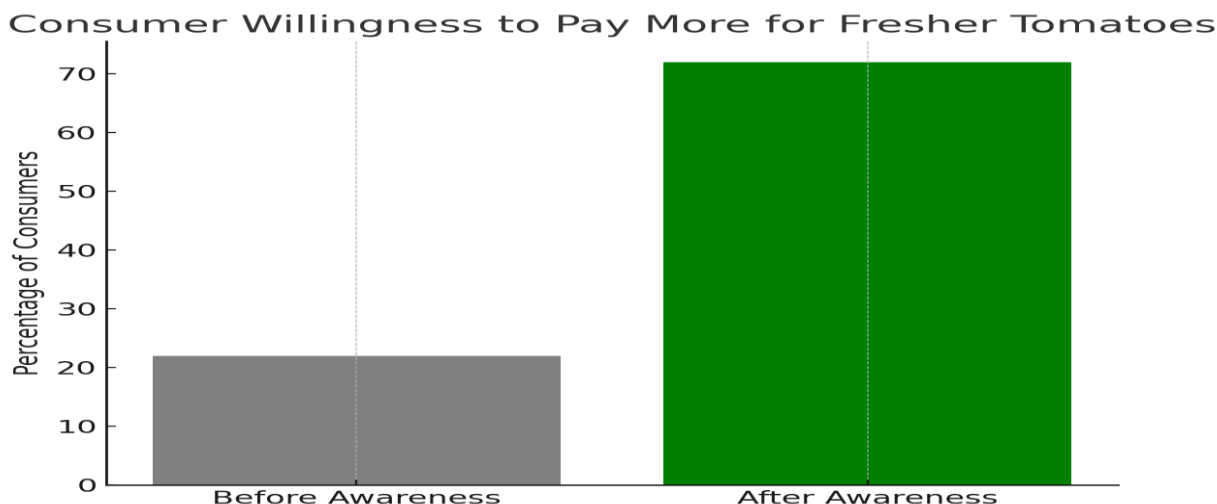
The results underscore deep-rooted systemic inefficiencies across all stages of Nigeria's tomato supply chain, with post-harvest losses posing a significant threat to food security, farmer income, and supply chain sustainability. These challenges, while diverse in form, are interlinked and stem from inadequate infrastructure, limited access to innovation, and weak coordination among stakeholders. **Interconnected Nature of Supply Chain Challenges:** The evidence suggests that inefficiencies at the production stage such as limited storage and input access create a domino effect across subsequent stages. Poor post-harvest handling at the farm level, compounded by inadequate transportation systems, contributes directly to the high spoilage rates observed during distribution. Furthermore, the lack of aggregation centers and cold storage facilities at markets leads to gluts and devaluation of produce, perpetuating financial losses for farmers and traders alike.

The Role and Potential of Cold Chain Solutions: The pilot deployment of solar-powered cold rooms and blockchain traceability platforms demonstrates clear potential in reducing spoilage, improving transparency, and increasing profitability. These technologies represent not just solutions to immediate storage issues, but foundational tools for modernizing and restructuring the entire value chain. However, uptake remains low due to barriers such as high initial investment costs, digital literacy gaps, and limited awareness particularly among smallholder farmers and rural traders. While stakeholders' express willingness to adopt such innovations, they often lack the capital, technical support, or policy incentives needed for meaningful integration.

Need for Holistic Interventions: The findings highlight that isolated interventions for example, focusing only on improved storage or market access are unlikely to yield long-term transformation. A systems-thinking approach is required, one that considers the entire chain from seed to consumer plate. Investment in rural infrastructure, digital extension services, education on post-harvest handling, and inclusive policy frameworks are essential.

Consumer Behavior and Market Dynamics: Interestingly, consumer preferences contribute subtly but significantly to market inefficiencies. The demand for visually perfect, "fresh" tomatoes

discourages traders from utilizing preservation technologies, even when they extend shelf life. Educational campaigns and awareness drives are necessary to shift consumer mindsets and align them with sustainable consumption practices. A major shift in consumer attitudes once they are made aware of the benefits of cold chain technologies.



4. Conclusion and Recommendations

This paper has examined the multi-dimensional challenges affecting Nigeria's tomato supply chain from production through to the consumer stage and evaluated the potential of sustainable cold chain solutions to mitigate post-harvest losses. The findings reveal that the inefficiencies in the supply chain are not isolated, but interconnected, with infrastructural deficits, poor handling practices, and lack of access to technology serving as major contributors to the persistent loss of produce. Sustainable innovations such as solar-powered cold storage and blockchain traceability systems offer promising avenues to enhance efficiency, reduce waste, and improve stakeholder profitability. However, for these solutions to be effective and scalable, they must be supported by targeted investment, policy reform, and capacity building. The study underscores the importance of a holistic, systems-based approach to supply chain development one that empowers producers, supports distributors, modernizes markets, and educates consumers.

Based on the findings and discussions, the following recommendations are proposed first, Strengthen Infrastructure and Logistics. This can be achieved through Investment in rural road networks to improve transportation efficiency and promoting the establishment of aggregation centers and mini cold storage hubs at production clusters. Secondly, Promote Adoption of Sustainable Cold Chain Technologies. Scale up subsidized access to solar-powered cold rooms through public-private partnerships. Also, provide microfinance and leasing models to support smallholder adoption. Encourage local fabrication of cold storage systems to reduce costs and improve accessibility. Thirdly, Enhance Stakeholder Capacity and Awareness; Launch training programs for farmers and traders on post-harvest handling and value addition. Conduct digital literacy campaigns to support the use of blockchain and traceability tools. Fourthly, Encourage Policy and Regulatory Support. Enact policies that incentivize cold chain investments through tax waivers or import duty exemptions. Integrate cold chain development into national agricultural and food security strategies. Also, foster consumer education through the implementation of awareness campaigns on the benefits of preserved produce to shift consumer perception.

Encourage consumption of locally grown, cold-stored produce as part of a sustainable food system. Lastly, facilitate multi-stakeholder collaboration.

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