Optimizing Efficiency: Mitigating Food Loss and Waste in Vegetable Supply Chain

Sidra Majeed
MPhil Scholar, Department of Economics and Agricultural Economics, PMAS, Rawalpindi

Majid Ali (Corresponding Author)
Assistant Professor, Department of Economics and Agricultural Economics, PMAS, Rawalpindi
Email: majidali@uaar.edu.pk

Arshad Mahmood Malik
Associate Professor/ Chairman Department of Economics and Agricultural Economics, PMAS, Rawalpindi

Abstract
Efficiency challenges persist throughout the agricultural food system, manifesting as food waste and loss across various points of the supply chain—from producers to intermediaries, wholesalers, retailers, and consumers. This study examines these inefficiencies specifically within the supply chains of three key vegetable commodities: tomato, onion, and potato in Rawalpindi district, Punjab, Pakistan. Through a multistage sampling approach, data were collected from 127 stakeholders, including commission agents, wholesalers, retailers, and consumers. Results highlight tomato as consistently experiencing the highest levels of food waste and loss across all supply chain stages, followed by onion and potato. Major inefficiencies identified are poor transport systems, improper packaging, and supply delays, leading to significant monetary losses at household and national levels. Addressing these inefficiencies can significantly reduce waste and enhance food security, promoting a more sustainable supply chain.
Keywords: Food waste, Vegetable supply chain, Tomato, Multistage Sampling Approach, Efficiency

I. INTRODUCTION
Inefficiencies within food supply chains arise from numerous inadequacies and inaccuracies occurring at various stages, including production, retail, wholesale, and consumption. These inefficiencies often lead to food waste and loss due to factors such as delays in commodity supply, poor inventory management, inadequate communication and collaboration among stakeholders, insufficient infrastructure, inefficient transport systems, and excessive bureaucratic regulations (Horton et al., 2019). Wasted and lost food embodies organizational, administrative, and social dimensions, reflecting unproductive resource use and indicating systemic inefficiencies across supply chains (Irani et al., 2018).

According to estimates by the World Economic Forum, approximately one-third of all food produced or distributed globally is lost or wasted, resulting in nearly $940 billion in economic losses (World Economic Forum, 2012). The occurrence of food waste and loss underscores inefficiencies within the processes where they occur. Horton et al. (2019) discuss various types of process efficiencies within the agricultural food system that, when compromised, contribute to inefficiencies. These include farm-level efficiencies (such as sunlight capture efficiency, photosynthesis use efficiency, biomass allocation efficiency, and harvesting efficiency), distribution efficiency (transport and storage), processing efficiency, retailing efficiency, and consumer-level efficiency (consumption and dietary efficiency). Harvesting efficiency refers to the incomplete collection of harvestable commodities, even with modern technology, highlighting inefficiencies in the harvesting process. Harvested commodities require transportation or immediate storage, and inefficiencies in storage and distribution can arise from inappropriate conditions, transport issues, and inadequate packaging (Horton et al., 2019).

Conceptually, food waste and loss differ: Irani et al. (2018) define food loss as the discarding of edible items occurring primarily in the supply chain from farming to processing, whereas food waste occurs at later stages due to consumer behavior. The Food and Agriculture Organization (FAO, 2020) distinguishes food loss as the wastage of crops and livestock exiting the supply chain before retail, including rejections that do not enter other uses. This includes losses across all supply chain stages, encompassing imported items and inedible portions separated from human food supply chains in retail, food service, and domestic sectors. Notably, food waste occurs at retail and consumer levels, whereas food loss occurs at producer and wholesaler levels (UNEP, 2021). Hortan (2021) defines food loss and waste across entire supply chains as indicative of food chain inefficiencies.

Given the complexity of food waste and loss, variations in commodity compositions and supply chain dynamics necessitate differentiated approaches (Ali et al., 2019). Each stakeholder in the supply chain encounters distinct challenges in executing their roles (Abbas, 2020). Kenneth et al. (2019) report that 24% of food is discarded during production and harvesting stages, with 35% wasted during consumption. Xue et al. (2022) suggest that nearly eighty percent of food is compromised during production, processing, and post-harvest stages.

While economic assessments are more common in developed nations, developing countries have begun focusing on this issue to raise awareness and reduce food waste (Khalid et al., 2022). Understanding the magnitude and hotspots of food waste and loss requires identifying their driving factors. Building on a global perspective, it is crucial to examine how these inefficiencies manifest in local contexts, such as Rawalpindi, Punjab.

Several studies in Pakistan have explored drivers of food waste and loss in specific sectors (Musa et al., 2018; Mumtaz et al., 2022; Khalid et al., 2022; Atique et al., 2021; WWF, 2020), yet none have comprehensively investigated food waste and loss across the entire supply chain and its economic implications, as proposed in this study. Food loss primarily occurs during production and wholesale stages, while food waste occurs at advanced supply chain stages, namely retail and consumer levels. This categorization guides the focus of the present study.

This study employs a multistage sampling technique, utilizing structured questionnaires to gather data from key stakeholders (wholesalers, commission agents, retailers, and consumers) at two major fruits and vegetable markets in Rawalpindi.

This study aims to investigate the inefficiencies contributing to food waste and loss among stakeholders (commission agents, wholesalers, retailers, and consumers) in the food supply chain of selected commodities (Tomato, Onion, and Potato - TOP) in Rawalpindi, Punjab. It seeks to identify the specific factors at each stage of the supply chain that lead to food waste and loss, ranging from production to consumption. Additionally, the study intends to determine the approximate volume and economic value of food waste and loss associated with these commodities in Punjab. By doing so, it aims to provide empirical data that can inform policy makers and stakeholders on effective strategies to mitigate food waste and loss in the local food supply chain, thereby promoting sustainable practices and reducing economic losses associated with inefficiencies.

II. LITERATURE REVIEW

This review synthesizes current research on food waste and loss in Pakistan, examining studies across various sectors of the food supply chain to identify consistent themes, key drivers, and gaps in understanding. Khalid et al. (2022) highlighted household-level food waste dynamics in Tehsil Kahror Pakka, District Lodhran, noting that high-income households generate more waste due to their ability to afford fresh food regularly. This aligns with Khalid et al. (2019), who found that cooked meals accounted for the highest waste volumes in the same district, indicating the need for targeted interventions.

Nazir (2022) identified eateries as major urban contributors to food waste and proposed operational strategies such as menu adjustments, staff training, and portion control. Complementing this, Basheer et al. (2021) reported significant waste rates for fruits and vegetables in Quetta, emphasizing supply chain dynamics and consumer behavior. Afzal et al. (2022) focused on Lahore's hospitality sector, identifying inaccurate forecasting and operational inefficiencies as primary contributors to waste. This supports Attique et al. (2021), who found that cognitive and emotional factors influence waste reduction behaviors among Pakistani consumers.

Mumtaz et al. (2022) used structural equation modeling to analyze consumer food waste behaviors in Islamabad and Rawalpindi, identifying environmental awareness, emotional considerations, and social norms as significant predictors of waste reduction intentions. Akram and Javed (2021) examined food waste in ceremonial settings in Sargodha, highlighting cultural norms and buffet service practices as drivers of waste during marriage ceremonies. Musa et al. (2018) and Ahmad et al. (2021) addressed food waste in Lahore's restaurant sector and post-harvest losses in Pakistan's agricultural sector, respectively, emphasizing the need for technological innovations and improved food management practices.

WWF (2020) reported substantial losses in rice and tomato supply chains across Pakistan, calling for integrated strategies to optimize resource use and reduce environmental footprints. Saeed and Khan (2010) examined tomato crop losses in Lahore markets, attributing significant losses to packaging, transportation inefficiencies, and distribution challenges. This review underscores the importance of context-specific interventions, stakeholder collaboration, and policy frameworks to promote sustainable resource management and minimize food waste.

Despite extensive research on food waste and loss in Pakistan, notable gaps persist. There is limited comprehensive research on the entire food supply chain from production to consumption, particularly in urban and peri-urban areas like Rawalpindi and Lahore. Additionally, there is a lack of longitudinal studies tracking changes in waste patterns and behaviors over time. While some studies have identified cultural and behavioral factors influencing food waste, there is a need for deeper exploration of socio-cultural norms and their impact on waste generation and mitigation strategies. Addressing these gaps is crucial for developing targeted interventions and policies to effectively reduce food waste and enhance resource efficiency across Pakistan's diverse food supply chains.

III. DATA AND METHOD

The study was conducted in District Rawalpindi using a multistage sampling technique suited for its market-based nature, involving all stakeholders in the fruits and vegetable markets. Commission agents and wholesalers from Islamabad and Rawat fruits and vegetable markets, along with randomly selected retailers and consumers from Rawalpindi city and its outskirts, participated. The focus was on potato, tomato, and onion due to their significant market presence and perishability.

A total of 127 respondents were included, as detailed in Table 1, to capture the perspectives of commission agents, wholesalers, retailers, and consumers within the supply chains of the selected commodities, despite resource and time constraints.

Table 1: Number of Respondents from Each Stakeholder

Stakeholder	Potato	Tomato	Onion	Total
Commission Agents	7	8	7	22
Wholesalers	10	10	10	30
Retailers	10	10	10	30
Consumers	15	15	15	45
Total	42	43	42	127

Data were collected using tailored, well-structured questionnaires designed for each stakeholder group. These questionnaires were pretested and adjusted based on feedback to ensure clarity and relevance, focusing on market activities, and food waste and loss. Commission agents, wholesalers, and retailers were interviewed in person, while consumer responses were collected via Google Forms. The data were analyzed using SPSS and MS-Excel, employing descriptive analysis techniques for clear interpretation.
This structured approach ensures robust insights into the dynamics of food waste and loss within Rawalpindi's vegetable supply chains, laying the groundwork for informed policy interventions and operational improvements.

IV. RESULTS AND DISCUSSION

The vegetable supply chain in Rawalpindi exhibits significant dynamics and challenges across various stakeholders, as evidenced by the gathered data on business volumes, waste/loss, and economic implications.

Volume of Business

Figure 1 presents the average weekly business volumes in maunds (1 maund = 40 kg) for potatoes, tomatoes, and onions among commission agents, wholesalers, retailers, and consumers. Potatoes emerge as the dominant commodity, particularly driven by the demand from fast food establishments, whereas tomatoes and onions also play substantial roles in the market.

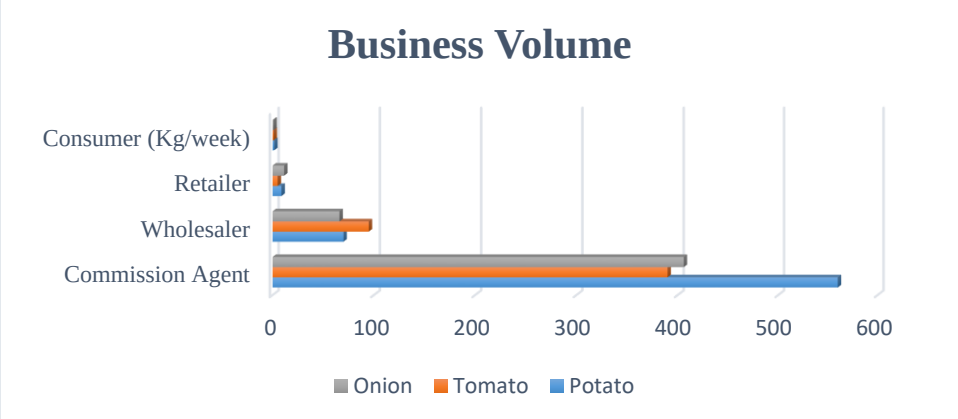

Figure 1: Average Business Volume (Maunds/week)

Commission agents stand out as pivotal figures in the supply chain, trading substantial volumes weekly. They handle 560 maunds of potatoes, 390 maunds of tomatoes, and 406 maunds of onions, leveraging their intermediary position between farmers and wholesalers to effectively manage supply and demand dynamics. This intermediary role enables them to minimize losses through informed decision-making and credit facilities for farmers, thereby maintaining a steady flow of produce to wholesalers and retailers (Basheer et al., 2021).

Wholesalers, predominantly located within market precincts, follow commission agents in handling tomato volumes, averaging 95 maunds per week, followed by potatoes (70 maunds/week) and onions (66 maunds/week). Meanwhile, retailers, typically serving localized consumer demand, reported sales volumes averaging 11.37 maunds of onions, 8.75 maunds of potatoes, and 5 maunds of tomatoes per week. In contrast, consumers purchase smaller quantities directly, averaging 1.5 kg of potatoes, 1 kg of tomatoes, and 0.81 kg of onions weekly per household, reflecting individual consumption patterns and affordability concerns (WWF, 2020).

Quantity of Vegetable Waste/Loss

Figure 2 provides insights into the average quantity of vegetable waste/loss along the supply chain. Commission agents report the highest losses per week, with 42.4 kg for tomatoes, 27.2 kg for potatoes, and 20.6 kg for onions. This early-stage loss primarily stems from quality deterioration, with minimal financial impact on commission agents due to their intermediary role. Wholesalers, handling reduced volumes post-retail transactions, report losses of 3 kg for tomatoes, 1.8 kg for onions, and 1.3 kg for potatoes weekly. Retailers, facing longer inventory holding periods, reported higher losses of 4.2 kg for tomatoes, 3.1 kg for onions, and 2.8 kg for potatoes weekly, underscoring the impact of inventory management practices on waste levels.

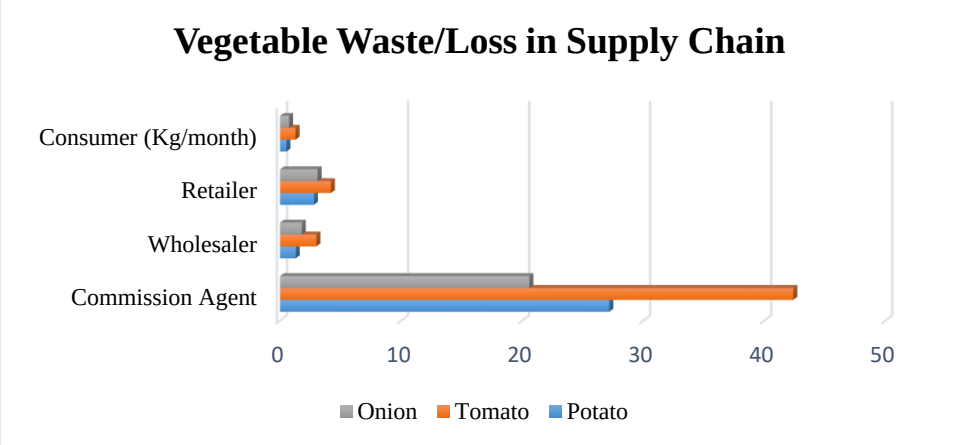

Figure 2: Average Quantity of Vegetable Waste/Loss in Supply Chain

Consumer-level waste varies across vegetables, with tomatoes exhibiting the highest wastage at 1.28 kg per household per month, followed by onions at 0.75 kg and potatoes with the least wastage due to their higher perishability awareness among consumers. Household budget constraints and increased awareness contribute to reduced waste at the consumer level, emphasizing the role of pricing and consumer behavior in waste mitigation strategies.

Vegetable Waste/Loss

Figure 3 outlines the average percentage rates of vegetable waste/loss in the supply chain. Commission agents report negligible losses (<1%) for all commodities, while wholesalers report higher percentages—3% for potatoes, 8% for tomatoes, and 2% for onions—reflecting their handling of reduced-quality produce post-retail transactions. Retailers report increased waste percentages—5% for potatoes, 11% for tomatoes, and 6% for onions—due to longer inventory stays, contrasting with consumer waste rates of 8.8% for potatoes, 18.2% for tomatoes, and 13.1% for onions, influenced by purchase quantities and household management practices.

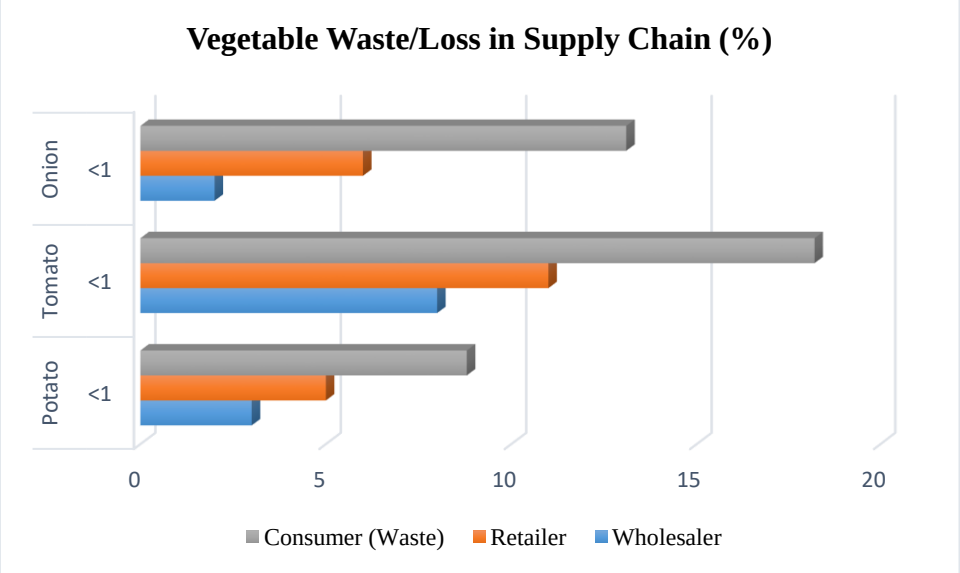

Figure 3: Average Rate of Vegetable Waste/Loss in Supply Chain (Percent)**

It was observed from the above discussion that vegetable waste/loss across different stakeholders in the supply chain. Tomatoes consistently show the highest levels of waste and loss, followed by onions and potatoes, reflecting their perishable nature and handling challenges at each stage of the supply chain.

Monetary Value of Vegetable Waste and Loss in Supply Chain

Figure 4 reports the monetary value of vegetable waste and loss per week in the supply chain. Commission agents incur the highest monetary losses due to their handling of large volumes, despite lower percentage losses. Retailers follow with significant monetary losses, attributed to consumer preferences for high-quality produce and longer inventory holding times. Wholesalers report relatively lower monetary losses, while consumers exhibit the least monetary waste due to reduced purchase quantities and enhanced household management practices.

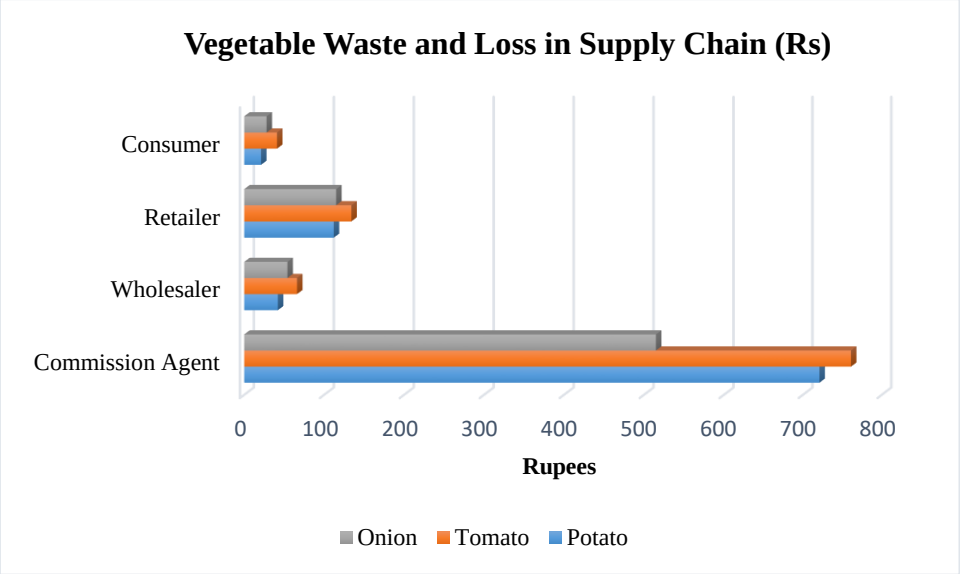

Figure 4: Average Value of Vegetable Waste and Loss/week in Supply Chain (Rs)

The vegetable supply chain in Rawalpindi faces multifaceted challenges, including substantial waste levels and economic repercussions across stakeholders. Commission agents play a crucial role in managing supply dynamics efficiently, supported by wholesalers and retailers who encounter varying levels of waste due to inventory management practices and consumer behavior. Consumer awareness and pricing strategies significantly influence waste mitigation efforts, indicating potential avenues for improvement through targeted interventions in storage, transport, and consumer education.

Average Loss and Waste per Annum (Millions)

The monetary value of food waste at the household level for three major vegetables, i.e., tomato, potato, and onion, is estimated using inferences and reported in Figure 5. The total population in Pakistan is around 241.4 million (Pakistan Bureau of Statistics 2023). While the average household size

reported by PBS is 6.3 persons, the total number of households in Rawalpindi is 0.98 million. Based on the estimation of the study, the average per month waste in monetary terms at the household level is Rs. 85 for potatoes, Rs. 164 for tomatoes, and Rs. 111 for onions, based on current price levels. Based on this inference, the total monetary loss in the district of Rawalpindi for three commodities at the household level is Rs. 83.3 million for potatoes, Rs. 160.7 million for tomatoes, and Rs. 108.7 million for onions monthly, while yearly it may exceed up to Rs. 999.6 million, Rs. 1928.6 million, and Rs. 1305 million for potatoes, tomatoes, and onions respectively, which is substantial. Using the same inferences for the national level, the yearly monetary loss for these three commodities may exceed up to Rs. 38997.4 million for potatoes, Rs. 7534.9 million for tomatoes, and Rs. 51046.1 million for onions respectively. This shows the extent of monetary loss every year along the supply chain of these three vegetable crops.

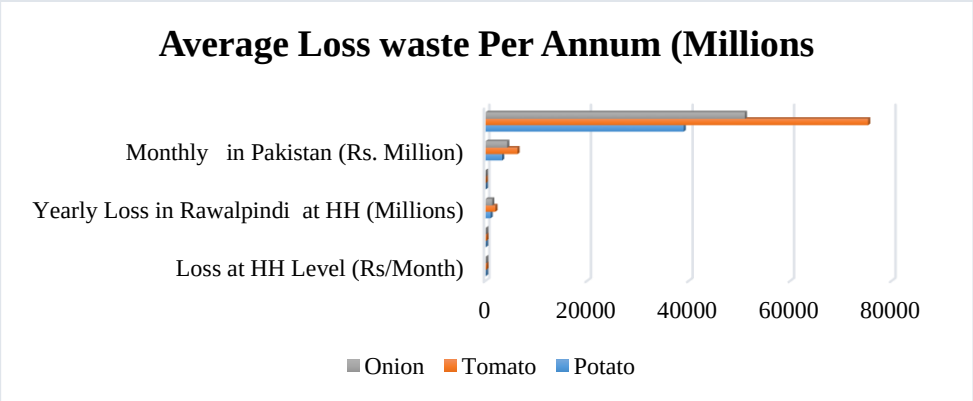

Figure 5: Average Loss waste Per Annum (Millions)

Supply Chain Inefficiencies

Based on the response from different supply chain stakeholders, inefficiencies are ranked on an ordinal scale depending upon the level of severity resulting in waste and loss of vegetables. Commission agents reported as in Table 2 inefficient transport systems, poor packaging, delays in supplies, and poor quality of vegetables as major concerns. Wholesalers ranked inappropriate packaging and poor quality of vegetables as major concerns. The retailers ranked overestimation of customer demand, poor quality of vegetables bought in packed form, inappropriate packaging, and inefficient transport systems as contributing factors to vegetable waste at the retail level. Consumers reported overbuying more than the requirements, inappropriate storage conditions, and purchasing misshapen produce as top inefficiencies, alongside busy schedules leading to waste.

Table 2: Inefficiencies contributing in vegetables waste and loss in supply chain

Vegetable	Ranks			
	I	**II**	**III**	**IV**
Commission Agent	Inefficient transport system	Inappropriate Packing	Delays in Supply	Poor quality of vegetables
Wholesaler	Inappropriate Packing	Poor quality of vegetables	Poor transport system	
Retailers	Over-estimation of consumer demand	Poor quality of vegetables	Inappropriate Packing	Inefficient transport facility
Consumer	Buying more than needed	Improper storage conditions	Bought in miss-happened condition	Busy schedule

Saeed and Khan (2010) calculated post-harvest losses of tomato crops in markets of the district Lahore and reported that the deterioration of the produce due to packing material was 25%, transportation system was 10%, and means of distribution was 5%, exceeding post-harvest losses up to 30%, and sometimes the whole lot is lost. These results are in line with the results of this study. Similarly, a study conducted by CABI (2018) reported that poor handling, storage, and transport systems contribute to losses of potato crops to the extent of 20-25%.

Complaints from Upstream Stakeholders of Supply Chain

The concerns of the upstream vegetables supply chain stakeholders are ranked using an ordinal scale and reported in Table 3. The wholesalers, who are either direct recipients of the vegetable supply or through commission agents, have top three concerns that include lack of freshness, inappropriate packaging, and inconsistent quality of vegetables. The retailers consider the lack of freshness as the top concern, which usually starts from the producer and continues throughout the supply chain. The second concern was the inconsistent supply of vegetables and inappropriate packaging. Lastly, customers consider the freshness of vegetables as the first concern, followed by inconsistent prices and the absence of a price list at the shops, which is the reason for the variation in vegetable prices and causes customer dissatisfaction due to this unfair market practice.

Table 3: Complaints from upstream stakeholders of supply chain

Vegetable	Ranks		
	I	**II**	**III**
Wholesaler to Producer	Lack of freshness	Inappropriate packaging	Inconsistent quality
Retailer to wholesaler	Quality and freshness	Inconsistent supply	Inappropriate packaging
Consumer to retailers	Freshness of vegetables	Inconsistent price	Absence of rate list at shops

Mitigating Strategies for Supply Chain Inefficiencies

Commission agents and wholesalers were surveyed to identify effective strategies for reducing food waste and loss in the vegetable supply chain, ranked in an ordinal scale as presented in Table 4. They emphasized the crucial role of proper packaging to minimize waste. Stakeholders highlighted the use of padding materials at the bottom and between layers of vegetables, particularly for highly perishable items like tomatoes. They also stressed avoiding overfilling and compressing top layers during packaging to prevent physical damage and decay. Additionally, stakeholders advocated for shorter auction periods for vegetables. Prolonged auctions increase the risk of spoilage and waste due to extended exposure and handling. Lastly, protocols for proper loading and unloading of vegetables were proposed to reduce damage and deterioration during transportation, thereby minimizing overall waste along the supply chain.

Retailers suggested several strategies aimed at improving storage conditions and reducing waste. They recommended controlling temperature and humidity levels by installing fans for better aeration, which can extend the shelf life of perishable commodities like vegetables. Retailers also emphasized the importance of meticulous monitoring and inventory control to promptly identify and remove deteriorated items from shelves before they spoil further. Moreover, the adoption of jute bags was highlighted as a sustainable solution to reduce waste, providing better breathability compared to plastic and helping maintain vegetable freshness during storage and transit.

Consumers play a pivotal role in reducing food waste through behavioral changes and proper handling practices. The top three strategies suggested by consumers, ranked by effectiveness, include adopting alternative shopping habits by purchasing smaller quantities more frequently rather than bulk buying. This practice reduces the likelihood of vegetables spoiling due to overstocking and improper storage. Consumers also emphasized the importance of proper and timely storage immediately after sorting vegetables at home. This includes storing vegetables in appropriate conditions such as refrigeration or cool, dry places to maintain freshness and extend shelf life. Additionally, consumers highlighted the use of freezing and preservation techniques to prolong the usability of vegetables, especially beneficial for busy schedules when immediate consumption is not possible.

Table 4: Mitigating strategies for supply chain inefficiencies

Vegetable	Ranks		
	I	II	III
Commission agents & Wholesaler	Proper packaging	Timely auction	Proper loading and unloading during transport
Retailers	Fan for aeration	Monitor and control inventory	Use of Jute Bags

Consumer	Buying less quantities more frequently than buying more quantities less frequently	proper and timely storage	Freezing and preservation

Most studies conducted in developing countries about food loss and waste indicate that one-third of produce is lost after harvesting. A recent report by the Ministry of National Food Security revealed that food waste is worth $4 billion annually. Table 9 explains the value of wastage/loss at the household level and household waste data is extrapolated for the Rawalpindi district and then at the national level. Potato, tomatoes, and onions are considered food security vegetable crops. Results indicate that on average, a worth of Rs. 360 of these three major vegetables is wasted at the household level monthly. If the loss is calculated monthly for Rawalpindi, around Rs. 352.7 million is wasted at the household level every month.

V. DISCUSSION AND CONCLUSION

The findings from the study provide a comprehensive understanding of the vegetable supply chain dynamics in Rawalpindi, highlighting significant inefficiencies and economic implications due to waste and loss. The analysis of business volumes, waste quantities, and economic impacts across various stakeholders underscores the critical areas that need attention to improve the overall efficiency and sustainability of the supply chain.

Commission agents, handling the largest volumes of vegetables, emerge as pivotal figures in the supply chain. Their role in managing the flow of produce from farmers to wholesalers is crucial for maintaining supply chain efficiency. The significant volumes of potatoes, tomatoes, and onions they handle reflect the high demand for these vegetables in the market, driven by consumer preferences and the food industry's requirements. Wholesalers and retailers, while handling smaller volumes compared to commission agents, also play essential roles in ensuring the availability of fresh produce to consumers. The data indicates that the consumer end of the supply chain purchases smaller quantities, influenced by household consumption patterns and affordability considerations.

The study reveals substantial waste and loss across the supply chain, with tomatoes exhibiting the highest levels of wastage. Commission agents report the most significant losses, primarily due to quality deterioration at the early stages of the supply chain. Retailers face notable waste levels due to prolonged inventory holding periods and consumer demand for high-quality produce. Consumers, while purchasing smaller quantities, still contribute to waste, particularly for perishable items like tomatoes and onions. The high wastage rates highlight the need for improved handling, storage, and transport practices to minimize losses and enhance supply chain efficiency.

The economic analysis underscores the significant monetary losses due to vegetable waste and loss. Commission agents incur the highest monetary losses, reflecting the large volumes they handle despite lower percentage losses. Retailers also face substantial monetary losses, attributed to

consumer preferences for fresh produce and inventory management challenges. At the consumer level, the monetary impact of waste, although smaller compared to other stakeholders, accumulates to significant amounts annually. The extrapolation of household-level waste data to district and national levels reveals staggering figures, indicating the urgent need for interventions to reduce these losses and improve food security.

The concerns of upstream stakeholders, including wholesalers and retailers, emphasize issues related to the freshness, quality, and packaging of vegetables. These concerns highlight the importance of addressing quality control measures at the production and initial handling stages to ensure that fresh and high-quality produce reaches the market. Consumers' complaints about inconsistent prices and the absence of rate lists at shops point to market practices that need regulation to ensure fairness and transparency in pricing.

The identified inefficiencies contributing to vegetable waste and loss include poor transport systems, inappropriate packaging, delays in supplies, and overestimation of consumer demand. These inefficiencies underscore the need for targeted interventions at various stages of the supply chain. Proper packaging, efficient transport facilities, and improved inventory management practices can significantly reduce waste and enhance the overall efficiency of the supply chain. The study also highlights the role of consumers in mitigating waste through behavioral changes, such as buying smaller quantities more frequently and adopting proper storage practices.

The proposed mitigating strategies provide actionable insights for stakeholders to reduce inefficiencies and minimize waste. Commission agents and wholesalers emphasize the importance of proper packaging and timely auctions to reduce spoilage. Retailers suggest improvements in storage conditions and inventory control to extend the shelf life of vegetables. Consumers can play a vital role by adopting better shopping habits, proper storage techniques, and preservation methods to reduce household-level waste. Implementing these strategies can lead to significant reductions in vegetable waste and loss, improving food security and economic sustainability.

The comprehensive analysis of the vegetable supply chain in Rawalpindi highlights significant inefficiencies and economic losses due to waste and loss. Addressing these challenges requires coordinated efforts across all stakeholders, from commission agents to consumers. By implementing targeted interventions and improving handling, storage, and transport practices, the supply chain can be made more efficient, reducing waste and enhancing food security. The economic implications of vegetable waste underscore the urgency of these measures, with potential savings running into billions of rupees annually. The study provides a roadmap for stakeholders to collaborate on reducing waste, ensuring the availability of fresh produce, and improving the overall sustainability of the vegetable supply chain in Rawalpindi.

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