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Multi-stakeholder collaboration framework for post-harvest loss reduction: the case of tomato value chain in Iringa and Morogoro regional in Tanzania

Fides John Izdori[1*], David Mkwambisi[2], Selma Tuemumunu Karuaihe[3] and Effie Papargyropoulou[4]

*Correspondence:
eng.fides@yahoo.com

[1] Department of Water Resources Engineering, College of Engineering and Technology, University of Dar es Salaam, Dar es Salaam, Tanzania
[2] MUST Institute of Industrial Research and Innovation, Malawi University of Science and Technology, Mikolongwe, Thylo, Malawi
[3] Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, Pretoria, South Africa
[4] School of Earth and Environment, Sustainability Research Institute, University of Leeds, Leeds, UK

Abstract

Globally, one-third of the food produced for human consumption globally is wasted, a figure projected to rise with increased food production. Collaborative efforts across food supply chains can mitigate post-harvest losses, playing a crucial role in enhancing food security. However, frameworks for multi-stakeholder collaborations remain underdeveloped, particularly in developing countries. We address this gap by focusing on the case study of tomato food supply chain in Tanzania. Using value chain analysis with farmers, traders, and transporters in the Iringa and Morogoro regions, findings reveal that 28% of post-harvest losses stem from climate and weather conditions, followed by limited market knowledge (12.5%) and inadequate storage facilities (11%). The results further show that only a small proportion of the tomato is transported to the market due to bad roads and there is limited number of processing industries, exacerbating the issue. Farmers have no knowledge as to how much they will produce or where they will sell in the next season. Building on these findings, the study revises Bhattacharya and Fayezi's (Ind Mark Manag 93: 328–343, 2021) framework to propose a tailored multi-stakeholder collaboration framework for the Tanzania food supply chain context. This framework aims to empower smallholder farmers to reduce losses and increase incomes while fostering sustainable collaborations applicable to other value chains and regions.

Keywords: Supply chain collaborations, Postharvest losses, Framework, Tomato smallholder farmers

Introduction

The current global population growth rate demands for increasing food production to satisfy food security, nutrition and health requirements (Daszkiewicz 2022; Oluwole et al. 2023). Approximately, one-third of food produced globally and 30% of food in Sub-Saharan Africa is lost before reaching consumers (Gustavsson 2011; Joensuu et al. 2021; Oluwole et al. 2023; AUC 2018; Sheahan and Barrett 2017). In Tanzania, food loss accounts for 30–40% of total annual crop production, with significant losses reported in fruits, vegetables, and root crops (URT 2019). These losses are projected to rise

alongside increased production, due to factors such as poor agricultural inputs, climatic variability, and inefficiencies in market chains (Oluwole et al. 2023; Joensuu et al. 2021).

Managing post-harvest food loss (PHL), which for the purpose of this study is the same as food loss as defined in (Parfitt et al. 2010), is critical for achieving food security, nutrition, and sustainable agriculture (Oluwole et al. 2023). Recent research highlights that interventions involving multiple stakeholders along food supply chains (FSCs) are more effective, as they address systemic dynamics (AUC 2018; Wagenberg et al. 2019; Bhattacharya and Fayezi 2021; Bustos and Moors 2018; Filimonau and Ermolaev 2021) as opposed to those targeting single actors or stages of the food chain (Gustavsson 2011). Multi-stakeholder interventions form what are known as "supply chain collaborations" that have a potential of reducing PHL through joint efforts to distribute risks and costs among stakeholders (Dania et al. 2018). Such collaborations foster innovation, facilitate institutional change, and reduce market inefficiencies, benefiting both producers and consumers (Drost et al. 2012; Gomez et al. 2020).

Despite these benefits, research on multi-stakeholder collaboration to reduce PHL in developing countries, particularly in Africa, remains limited (Bhattacharya and Fayezi 2021). Even though, literature shows the presence of collaborative interventions for PHL among FSC actors and within the food system in developing countries (Chegere et al. 2020; Wagenberg et al. 2019), they have yet to significantly benefit smallholder tomato farmers who still face low productivity and high PHL (Mutayoba and Ngaruko 2018; Ombaeli et al. 2022). Furthermore, the collaborative interventions that show the potential of reducing PHL in developed countries need to be adopted to local context prevalent in developing countries. It is also reported that the current FSCs in developing countries as well as power dynamics do not favor collaborations for PHL reduction, despite the reported high losses (Bustos and Moors 2018). We align our thinking that forming collaborations entails formalization of governance structures and establishing arrangements that specify objectives, activities, roles and responsibilities of the stakeholders involved (Bitzer 2011; Bhattacharya and Fayezi 2021).

Formation of stakeholders' collaborations for PHL in developing countries requires consideration of all these issues. A framework to reduce PHL among tomato farmers, however, seems to be missing (Rutta 2022; Njume et al. 2020; Ugonna et al. 2015). As such, food losses and waste, government support and resource allocation is based on learning from other sectors. Institutions to support farmers with finances provide innovation extension services are failing to see the link between collaboration and improved farmer livelihoods due to lack of a conceptual framework. A conceptual framework developed by Bhattacharya and Fayezi (2021) illustrates the collaboration conditions and how navigating them may result in formation of strong multi-stakeholder collaborations for reducing food loss and waste (FLW). However, this framework is generalized for both food loss and food waste and therefore assumes uniformity in developing countries where the former is prevalent and developed countries where the latter is typical.

This research therefore seeks to explore the prevalent conditions that cause PHL along the FSC in developing countries and use these to customize the framework. The tomato FSC is chosen as a case study considering its substantial contribution to the total annual household income and poverty reduction (de Putter et al. 2007), as well as its high perishability and subsequent post-harvest losses that are estimated to be as high as 50%

(URT 2019). Furthermore, tomato is the most grown horticultural crop in the country, grown mostly in Iringa and Morogoro regions (de Putter et al. 2007). Our empirical work titled 'multi-stakeholder collaboration framework for post-harvest loss reduction' modified from (Bhattacharya and Fayezi 2021), seeks to (i) understand the causes of PHL in the two study regions of Iringa and Morogoro (ii) analyze the role of stakeholders along the tomato value chain, and (iii) develop a stakeholder collaboration conceptual framework that supports farmers in reducing PHL.

The proposed framework is expected to provide an overarching structure that guides policy formulation and governance among smallholder tomato farmers in Tanzania. In addition, the proposed framework advocates for empowering smallholder farmers to increase their collaborative advantage. This will result into formation of stronger and more successful collaborations among FSC stakeholders that aims at reducing PHL, which may be adopted and scaled-out to other value chains and other regions.

Conceptual background

Conceptual frameworks

Conceptual frameworks are essential tools in research and practice, providing structured ways to understand, analyze, and address complex issues. They offer a theoretical basis for organizing ideas, guiding research questions, and interpreting findings. They provide a visual representation of the study's structure, making it easier to identify gaps in knowledge and formulate research questions (Maxwell 2013). A well-constructed conceptual framework serves as a guide for data collection and analysis (Ravitch and Riggan 2017). Conceptual frameworks are widely used across various disciplines, including social sciences, education, health, and business. They are particularly valuable in fields where complex, multifaceted phenomena such as the issue of PHL need to be studied. A framework for stakeholders' collaboration in reducing PHL requires a logical and thorough examination of a specific FSC to generate new ideas and concepts on issues affecting it (Downs 2007; Midgley 2007). The development of a conceptual framework involves synthesizing existing theories and research to create a new, coherent structure. The framework which this work builds upon emanates from the work by (Bhattacharya and Fayezi 2021) as discussed below.

The framework for ameliorating food loss and waste in the supply chain through multi-stakeholder collaboration by Bhattacharya and Fayezi's (2021)

The Bhattacharya and Fayezi's (2021) study explored how multi-stakeholder collaborations can help reduce food loss and waste (FLW) from the end-to-end food supply chains. It investigated the way various "conditions" can prohibit alignment between stakeholders resulting in FLW, and how stakeholder can collaborate to reduce FLW. The framework begins with categorizing stakeholders into core and supporting stakeholders. The core stakeholders are those responsible in bridging the gap between growers on the upstream and consumers on the downstream. These include growers, processors, distributors, manufacturers, wholesalers, retailers, food service businesses, and consumers. On the other hand, supporting stakeholders are those who support the core stakeholders in reducing FLW from the food supply chain through design of policies/regulations and development of technologies. These are such as NGOs, government and government

agencies, financial institutions, scientific organizations, universities, industry regulatory bodies/associations, and global organizations.

Two sets of conditions were identified as prohibiting alignment of stakeholders' interests to form collaborations. These were termed as structural and sporadic conditions. The structural conditions are related to the process of product delivery as well as its quality and originate from the actions of the core value chain actors in the FSC. The structural conditions are such as poor infrastructure, limited access to markets, lack of processing industries, etc. On the other hand, the sporadic conditions arise from the action of supporting value chain actors and include awareness campaigns, policies, regulations, and frameworks.

The framework calls upon both vertical and horizontal collaborations, respectively among core and supporting stakeholders in reducing post-harvest losses along the value chain. The framework is confirmed through a systematic literature review and case studies from different parts of the world. The collaborative conditions upon which stakeholders build collaborations are termed as sporadic for the supporting stakeholders and systematic for the core stakeholders. These influence the alignment of stakeholders' interests and hence collaborative advantages (Caldeira et al. 2019; Gustavsson 2011; Sheahan and Barrett 2017)).

The framework by Bhattacharya and Fayezi addressed both issues of food loss and food waste (FLW). However, the distinction between food loss and food waste, based on the stage at which they occur, and the region's level of economy indicates a need for separate interventions to address them. Food loss is defined as harvested food that never makes it to consumer tables for various reasons while food waste is the food discarded at consumption level (AUC 2018; Wagenberg et al. 2019). Research shows that in low- and middle-income countries, highest FLW occur at the post-harvest level while in high income countries highest FLW occur at consumption level as food waste (Gustavsson 2011). Therefore, the stakeholders involved as well as the roles they play in collaborations are different. Our study aims at elaborating this difference and customizes the framework by Bhattacharya and Fayezi, (2021) to address PHL in the context of the Iringa and Morogoro tomato producing regions in Tanzania, using the empirical insights from these two case studies.

Drivers of food loss in developing countries

Food loss in Africa is a significant challenge, affecting food security, economic development, and environmental sustainability. These losses occur during transportation, storage, and distribution due to delays, spoilage, and exposure to pests and diseases (Kumar and Kalita 2017). The lack of cold storage and efficient transportation exacerbates the situation (Affognon et al. 2015; Gustavsson 2011). Farmers in remote or rural areas often lack access to markets where they can sell their produce quickly (Gustavsson 2011). Financial barriers, such as limited access to credit and capital, prevent farmers from investing in better storage facilities, transportation, and technologies that could reduce food loss (Kaminski and Christiaensen 2014). The inefficiencies in supply chains, including a lack of coordination among stakeholders, lead to delays, mismanagement, and food loss at various stages from production to consumption (Gustavsson 2011; Parfitt et al. 2010). Climate change impacts, such as increased temperatures, unpredictable rainfall

patterns, and extreme weather events, contribute to food loss by affecting crop yields and increasing the vulnerability of crops to pests, diseases, and spoilage (Gustavsson 2011; Sasson 2012). Factors such as improper drying, packaging, and storage conditions expose produce to pests, mold, and spoilage (Sheahan and Barrett 2017). Also, many smallholder farmers lack access to training and knowledge about modern post-harvest handling and storage techniques (Kitinoja et al. 2011).

Methodology

This section outlines the details of the research design and methods followed in this study. It explains some of the key assumptions and implications resulting from the sampling choices made in providing this first assessment of the role stakeholders play in the tomato value chains of the study areas in reducing food loss and waste and contributing toward smallholder farmers income.

Study area

To address the objectives of this research, two case study areas (Iringa and Morogoro regions) were selected from the highest tomato producing regions in Tanzania according to the 2016/17 Annual Agriculture Sample Survey of Tanzania report (URT 2016). First region is Iringa, which lies at an altitude of 475 m above sea level with high peaks of 2981 m above level and has a mild climate with average temperatures of 10 °C in May/June and up to 25 °C during October. Annual rainfall in Iringa ranges from 500 to 1600 mm annually. Tanzania has two tomato processing industries in Iringa. The second region is Morogoro, with average temperatures between 18 and 30 °C. Annual rainfall ranges between 600 and 1800 mm, except for the Eastern parts of the Uluguru mountains which receives high rainfalls of up to 2850 mm annually, while the leeward sides receive less than 600 mm annually. The households in these regions are dominated by smallholder farmers forming about 90 percent of the population (URT 2012, 2022). Weather conditions are the major determinant of agricultural performance in the study area.

Research design

Mixed methods for data collection and analysis were used to enhance the validity and reliability of the findings. Qualitative data were gathered through field observations, focus group discussions (FGDs) with farmers, traders, transporters, and local leaders, while quantitative data were collected via a farmer survey. A multistage sampling technique was used in selecting respondents (Schreinemachers et al. 2015). Purposive sampling identified one district in each region—Kilolo in Iringa and Mvomero in Morogoro—based on high tomato production. Subsequently, three wards in each district were purposively selected: Ilula, Lugalo, and Ruaha Mbuyuni in Kilolo, and Mlali, Doma, and Melela in Mvomero. Respondents were randomly selected with the assistance of Village Extension Officers. Other value chain actors were identified by snowballing from the consulted farmers, and represent individuals (farmers, traders and transporters) who are either directly or indirectly involved with the farmer in tomato production.

The farmer survey targeted 280 participants, comprising 167 farmers (51 women, 116 men) from Kilolo and 113 farmers (27 women, 86 men) from Mvomero. The survey included questions on socio-economic and demographic characteristics, farming

practices, land ownership, and challenges faced during production and post-harvest stages. Information on constraints in post-harvest practices was collected, focusing on perceived environmental issues, policy and regulatory frameworks, transportation, input supply, and institutional support.

For objective one which aims to establish the common causes of PHL in the case study areas, we first reviewed literature to list common causes of PHL. Using participatory approaches, list of the common causes of PHL was discussed together with the farmers to (i) choose those applicable to them and (ii) rank them starting with those that affect them most, using same number for those affecting them equally. A field named "other" was provided for farmers to mention any other causes that were not in the list and rank them.

To address the second objective that deal with analyzing the roles of stakeholders along the tomato value chain, we used the stakeholder analysis approach. Qualitative data was collected to characterize the FSC and identify stakeholders involved on the farmside through focus group discussions (FGDs) with groups of farmers, traders and transporters. A total of 12 farmers FGDs (7 in Kilolo and 5 in Mvomero), 8 traders FGDs (6 in Kilolo and 2 in Mvomero), 8 transporters FGDs (5 in Kilolo and 3 in Mvomero) and 5 leaders FDGs (5 in Kilolo and 2 in Mvomero) were conducted in groups of 6 to 12 participants in both Kilolo and Mvomero districts. The tools used in the survey and FDGs were fed into the mWater software and are available on request.

Finally, to address our third objectives, which deals with developing a stakeholder collaboration conceptual framework that supports farmers in reducing PHL, we used literature review to identify a conceptual framework that was fitting into our study context. The components of the framework were fully analyzed to identify areas that are relevant to our study as well as to identify gaps. Building on objective 1 and 2, we modified the framework to fit into the Tanzanian context. We first established the different collaboration "conditions" that prohibit alignment between stakeholders to reduce PHL in the tomato FSC in Iringa and Morogoro regions of Tanzania. We then explored how the interplay between different conditions and stakeholder orientations can be aligned to support stakeholder collaborations in reducing PHL.

Data analysis

Analysis of quantitative data from the farmers' survey was done in spreadsheet for frequencies to rank the responses of the causes of PHL. Furthermore, the value chain framework was used in this study to analyze the flow of tomatoes from production to the point of transportation outside the farm areas. This analysis identified the actors involved in production, processing, trading, and transportation, highlighting inefficiencies contributing to PHL. Then, stakeholder analysis which refers to a range of approaches for the identification and description of stakeholders based on their attributes, interrelationships and interests related to a given project was employed (Bezabih et al., 2020). Stakeholder analysis identified linkages among actors by considering all activities and processes along the tomato value chain, from input supply to end users. Adopting the salient stakeholder theory by Mitchell et al. (1997) as outlined in (Surucu-Balci and Tuna 2021), core or leading stakeholders in collaborations were identified. The quantitative data enabled identification of the causes of PHL and the magnitude of their

impacts. The qualitative data was used in establishing the weaknesses in the FSC and establishing the stakeholders involved and their roles.

Results

Causes of PHL

The causes of post-harvest loss (PHL) as ranked through the farmer survey in Kilolo and Mvomero districts are presented in Fig. 1. Climate and weather conditions were ranked as the primary causes of PHL by farmers in both districts, reflecting their significant impact on agricultural outputs. In Kilolo district, the second major cause was a lack of market demand knowledge, followed by insufficient storage facilities. In contrast, in Mvomero district, the second-ranked cause was improper handling of tomatoes during harvesting and marketing, with limited knowledge of post-harvest technologies ranked third.

Farmers consistently emphasized the role of unpredictable rainfall and prolonged dry spells in contributing to both pre- and post-harvest losses. Heavy rains exacerbate price fluctuations due to the damage caused to road and market infrastructure, restricting farmers' market access. Additionally, poor road conditions in Kilolo and reliance on motorcycles for transportation further increase the risk of PHL, particularly when transporting ripe tomatoes.

Traditional practices such as overfilling crates during packaging, observed in Ruaha Mbuyuni, were identified as another contributing factor. This practice exerts pressure on tomatoes at the bottom of crates, causing bruising and reducing shelf life. The absence of proper storage facilities also forces farmers to sell quickly, often at unfavorable prices, further increasing losses.

The findings highlight the multifaceted nature of PHL, rooted in environmental, infrastructural, and market-related challenges. Addressing these issues requires interventions targeting infrastructure improvements, capacity-building for farmers, and the promotion of proper post-harvest practices.

The FSC stakeholders and their roles

The food supply chain

The food supply chain (FSC) describes the processes tomatoes undergo from production to consumer tables. However, this study focuses on the farmside stages of the

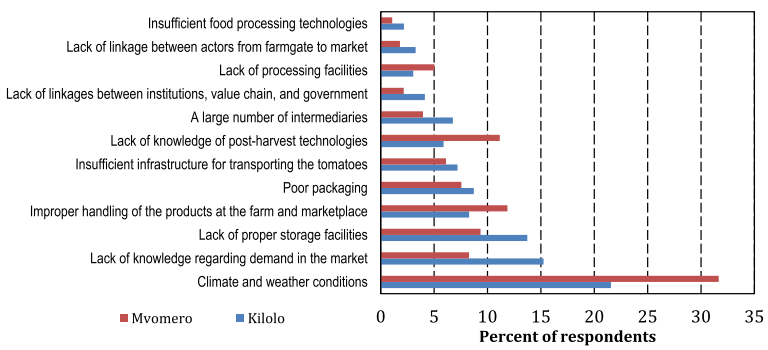

Fig. 1 Ranking of the causes of tomato PHL by farmers in Kilolo and Mvomero districts

supply chain, up to the point where tomatoes leave the farming areas. The FSCs in Iringa and Morogoro differ slightly in structure and performance due to regional variations in infrastructure and market access.

In Iringa, the FSC comprise five stages which are (i) production (ii) local/farmside transport (iii) marketing and packaging (iv) processing and (v) Transport outside farm areas. Farmers in Iringa rely heavily on middlemen to access markets, creating an additional layer that influences pricing and decision-making. In contrast, the FSC in Morogoro has four stages which are (i) production (ii) local/farmside transport (iii) marketing and packaging and (iv) transport outside farm areas. The actors in the tomato supply chains of the study areas are presented in Fig. 2. Morogoro lacks processing industries, which limits value addition opportunities for farmers. Traders in this region predominantly purchase produce directly at the farm gate, bypassing middlemen.

The FSC in the two case study areas are fragmented, which is typical for developing countries. Farmers rarely know who their buyers will be in the next season, nor can they predict production volumes or potential markets for their produce. This uncertainty, combined with a lack of formal contracts between farmers and other FSC actors, exacerbates post-harvest losses. Literature reports relatively low food losses in developed countries as compared to food waste due to well organized, influential, and functioning FSC and supporting environment (Verghese et al. 2013). The FSCs in these countries are characterized by chain supermarkets, large-scale commercial farmers and supporting environment like charity shops where food can be donated or sold at a cheaper price to reduce food losses. Such actors are non-existent in both case study regions.

Addressing these challenges requires strengthening the FSC through improved infrastructure, better market access, and the establishment of formalized agreements

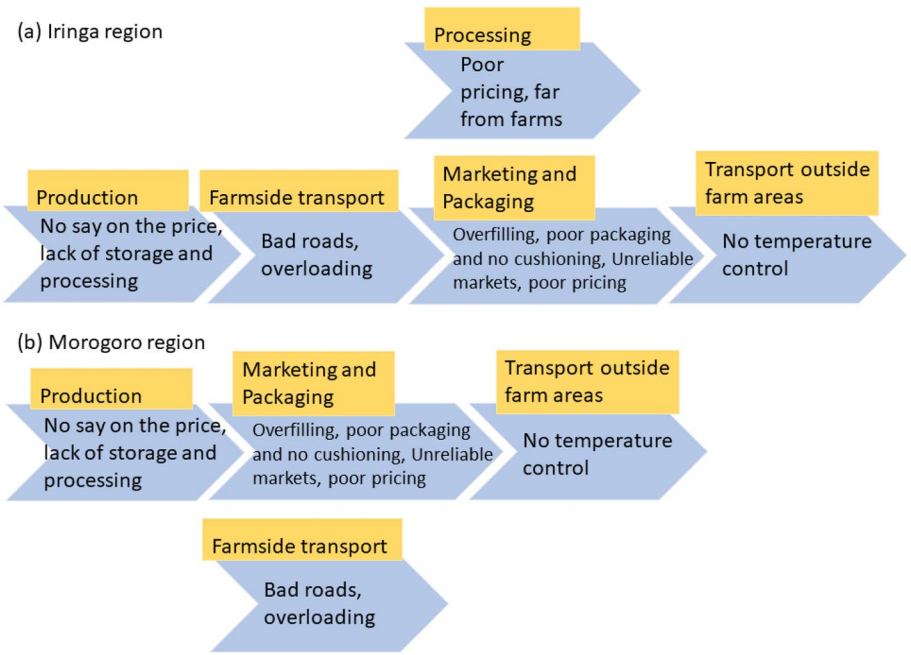

Fig. 2 The identified issues at different stages of the tomato supply chain in the study areas

between farmers and other stakeholders. Furthermore, creating more stable and predictable supply chains can help reduce losses and increase farmers' incomes.

The FSC stakeholders and their roles

Stakeholders in the food supply chain (FSC) are categorized into two groups of core and supporting stakeholders. Core stakeholders are directly responsible for moving produce from production to consumption (Bhattacharya and Fayezi 2021). These include smallholder farmers, collectors, traders (wholesalers, retailers, and exporters), and processors. Without these actors, the FSC cannot function effectively. Supporting stakeholders, on the other hand, provide crucial services and resources to address FSC inefficiencies. These include non-governmental organizations (NGOs), government agencies, financial institutions, researchers, and other industry actors.

In the study areas, smallholder farmers dominate tomato production but face significant challenges, including limited resources, lack of formal education on agronomic practices, and minimal influence in the FSC. Furthermore, the absence of proper storage facilities, poor road networks, and a lack of processing industries force farmers to sell their produce quickly to avoid spoilage, but this leaves them vulnerable to exploitation by other FSC actors, such as traders and processors, who prioritize maximizing their profit margins. Also, there are no formal contracts or consistent relationships between farmers and buyers, exacerbating uncertainty and reducing farmers' bargaining power.

Traders, collectors, and transporters play a vital role in ensuring that produce moves efficiently through the FSC. However, in both Iringa and Morogoro, these actors often exploit farmers due to their limited access to alternative markets. The lack of proper storage and transportation facilities further increases farmers' dependence on these intermediaries.

Supporting stakeholders are essential in addressing these challenges. For example, NGOs and research institutions often provide technical training, advocate for better policies, and introduce innovations aimed at reducing post-harvest losses. Government agencies can facilitate these efforts by creating enabling environments through supportive policies and infrastructure investments.

To strengthen the FSC and reduce PHL, it is critical to enhance the coordination and alignment between core and supporting stakeholders. This includes formalizing relationships between farmers and other actors, improving access to storage and transportation infrastructure, and ensuring farmers have access to the resources and knowledge necessary to improve their practices.

Proposed Stakeholders' collaboration framework for PHL reduction

The Bhattacharya and Fayezi framework and identified gaps

The Bhattacharya and Fayezi (2021) framework served as the foundation for this study, offering insights into multi-stakeholder collaborations to reduce food loss and waste (FLW). However, certain gaps were identified, particularly regarding the context of developing countries. The revised framework addresses these gaps by emphasizing the unique challenges faced by smallholder farmers and tailoring solutions to the conditions of the Tanzanian tomato value chain.

Structural conditions, as identified in the original framework, relate to systemic issues within the food supply chain (FSC), such as inadequate infrastructure, limited market access, and a lack of processing industries. In the Tanzanian context, structural conditions are heavily influenced by government interventions, including regulatory policies, extension services, and research and development. These interventions are essential for creating a supportive environment that enables stakeholders to collaborate effectively.

Sporadic conditions, on the other hand, include awareness campaigns, policy gaps, and uncoordinated efforts by supporting stakeholders. While these conditions were identified as secondary in the original framework, the revised framework highlights their critical role in addressing weaknesses within the FSC identified in Section "The FSC stakeholders and their roles". Education and awareness-raising campaigns are necessary to improve farmers' use of inputs, packaging, and storage technologies.

The revised framework also redefines vertical and horizontal collaborations based on issues in Section "Causes of PHL" and "The FSC stakeholders and their roles". In this framework, vertical collaborations occur between diverse stakeholders, such as farmers, government agencies, and financial institutions, while horizontal collaborations involve stakeholders within the same category, such as farmer associations or trader cooperatives. This distinction is vital in strengthening the FSC by ensuring alignment among stakeholders with complementary roles.

A central aspect of our revised framework is the empowerment of smallholder farmers by placing farmers at the center of the framework to ensure their inclusion in decision-making processes and providing mechanisms for building their capacity. We also propose establishing farmer associations as a strategy to enhance their bargaining power, facilitate access to markets, and improve the efficiency of collaboration with other FSC actors.

We further introduce feedback loops into the framework to allow continuous improvements based on stakeholder experiences. These loops ensure that policies, interventions, and collaborations remain adaptive to emerging challenges and farmer needs. By addressing both structural and sporadic conditions, the revised framework aims to create a more resilient and efficient tomato value chain in Tanzania.

Discussion of results

Causes of PHL: weaknesses in the FSC

This study sought to examine the drivers of post-harvest loss (PHL) in the tomato value chain in Iringa and Morogoro regions of Tanzania and propose a framework for reducing PHL through multi-stakeholder collaboration. The findings highlight the multifaceted nature of PHL, rooted in climatic, infrastructural, and market-related challenges. Farmers in both regions identified climate variability, including unpredictable rainfall and prolonged dry spells, as the leading cause of PHL. Heavy rains exacerbate these losses by damaging roads and market infrastructure, limiting access to markets and increasing spoilage.

The high ranking of weather and climate conditions is due to the impact on both pre- and post-harvest losses. The farmers' high dependency on rainfall coupled with increased dry spells due to climate change affect farmers in all districts. To cope with this, the farmers practise "mixed farming" where they resort to irrigation when there is

no rain. However, the high capital cost for installing the irrigation system is a barrier for farmers to practise irrigation agriculture, despite the knowledge of its benefits. Weather, specifically heavy rains is also a major cause of price fluctuations, due to the impact it has on road and market infrastructure. Limited access to road infrastructure results into limited access to markets and other services, hence increasing farmers' vulnerability to shocks and likelihood of falling deeper into poverty (Gomez et al. 2020).

Lack of information regarding demand and their price fluctuations in the market causes overproduction (Raut et al. 2018). This coupled with lack of proper storage facilities result into losses to farmers. Harvesting ripe tomatoes as opposed to green tomatoes is common in developing countries (Njume et al. 2020; Ugonna et al. 2015) and is also practiced in both districts. It is linked to bruising, shorter shelf life and hence increased PHL in the absence of immediate markets and proper storage facilities. Also, the bad roads in Kilolo and the practice of transportation using motorcycles exacerbate PHL especially where ripe tomatoes are concerned.

Most farmers are cultivating tomato by experience. Their engagement with the scientific community is very low. Few consult agricultural officers but most rely on fellow farmers and input suppliers for advice. This results in all types of misconduct which end in PHL. For example, in Ruaha Mbuyuni, packers were seen overfilling crates and compact/press them to accommodate more tomatoes in a crate, which further contributes to losses by reducing the quality and shelf life of tomatoes.

In summary, it was found that during production, there is no proper market information for farmers to make decision on type of produce, quality or even farm gate prices. At this stage, the farmers have no storage or processing facilities. During transportation, the farmers are faced with bad roads, overloading of produces, overfilling, poor packaging and unreliable markers. Lastly, once the produce leaves the farm and are at marketing stage, common issues in both regions include distance (markets are far from the farms), limited transport around the farming areas, poor pricing and no cooling facilities.

The FSC stakeholders and their roles in collaborations

Similar to the findings of Bhattacharya and Fayezi (2021) for developing countries' food supply chains (FSCs), smallholder farmers dominate the production sector in both study areas. However, existing exploitative conditions and the disadvantaged position of smallholder farmers (Drost et al. 2012; Gomez et al. 2020) prevent them from having the same level of power and influence as other FSC actors. This highlights the need to acknowledge and address the structural imbalance within the FSC. Also, the capacity of smallholder farmers to invest in post-harvest loss (PHL) reduction strategies, such as cold storage and improved inputs, remains limited (Rutta 2022). Without external support, many farmers are unable to adopt measures that could reduce losses and improve productivity. Government-led interventions, including subsidies and support programs, have shown positive outcomes in improving farmers' resilience and capacity to address PHL challenges. To enhance collaborations within the FSC, there is a need for deliberate efforts to register and engage supporting actors who can advocate for and assist smallholder farmers. This role can be effectively played by the government through targeted policy interventions, such as creating incentives for NGOs, financial institutions, and private actors to work closely with smallholder farmers. By aligning the interests of core

and supporting stakeholders, these efforts can reduce power imbalances and foster more equitable and effective collaborations.

Proposed Stakeholders' collaboration framework for PHL reduction

Addressing the gaps in the Bhattacharya and Fayezi framework

To address the gaps identified in 4.3, we modified the framework to come up with the framework in Fig. 3. We adopt Bhattacharya and Fayezi's definition of structural conditions as those related to the structure of the food supply chain (FSC) and argue that addressing these conditions begins with creating a structured and well-functioning FSC (Bustos and Moors 2018). This includes establishing an enabling environment, such as regulatory services, to improve FSC efficiency and reduce post-harvest loss (PHL). In Tanzania, this role can be performed better by the government based on parliamentary approved policies and acts that may not be changed within a short time. However, government interventions must be research-informed and communicated to farmers via extension services, making the government, research institutions, and extension services core stakeholders in creating efficient FSCs.

The framework positions the government, research, and extension services as core stakeholders, with all other actors categorized as supporting stakeholders. Among supporting stakeholders, we distinguish between main supporting actors, who are essential for moving food along the FSC (e.g., traders, transporters, processors), and secondary supporting actors, who provide auxiliary services (e.g., NGOs, financial institutions). This distinction ensures policies can be tailored to address the unique roles of different actors.

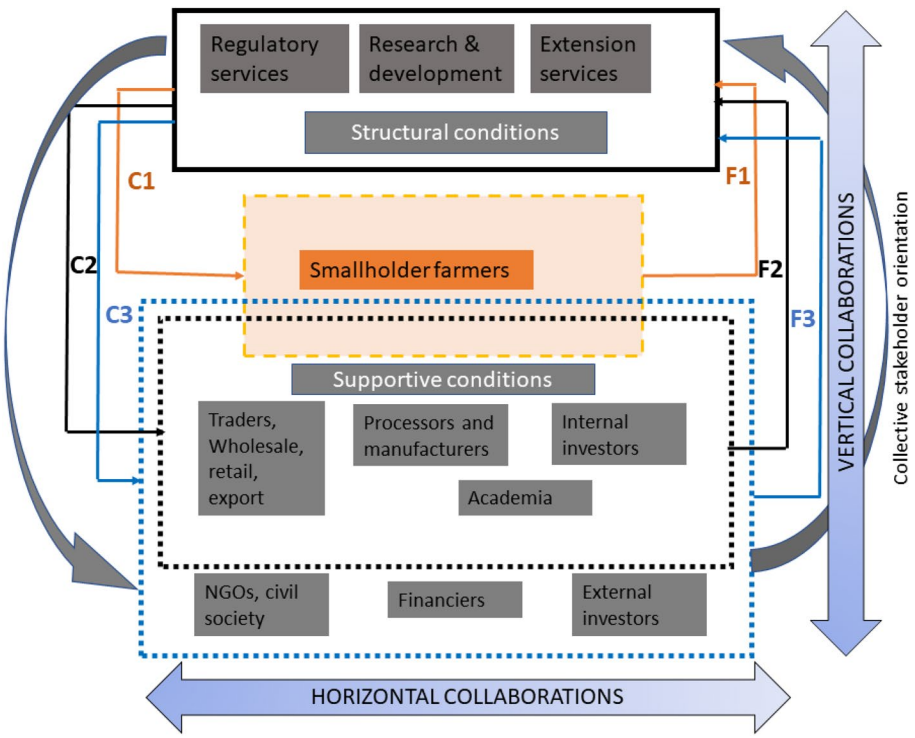

Fig. 3 Proposed framework for stakeholders' collaboration for reducing PHL

Secondly, we propose redefining the "supporting stakeholders" identified in the original framework as "core stakeholders" for PHL reduction, as they play a more central role in addressing PHL. Actions of growers, processors, distributors, manufacturers, wholesalers, retailers and consumers tend to increase PHL, while the actions of NGOs, government and government agencies, financial institutions, scientific organizations, universities, industry regulatory bodies/associations, and global organizations tend to reduce PHL (Bhattacharya and Fayezi 2021), making them "core" stakeholders in reducing PHL. Therefore, in the proposed framework, the supporting stakeholders are all other stakeholders apart from government and government agencies, research and development and extension services.

Thirdly, the proposed framework places smallholder farmers at its center, with mechanisms to empower them through farmer associations. These associations can act as representative bodies for engaging with other stakeholders and improving farmers' bargaining power. Studies show that farmer associations influence profitability (Mwatawala et al. 2019) and mitigate collaboration failures caused by poor organization (León-Bravo et al. 2017). Associations can also improve the farmers' capacity to deliver consistent volumes, meet quality standards, and ensure a steady supply (Drost et al. 2012). However, for associations to succeed, structural conditions must include clear rules and regulations (C1 in Fig. 3) and continuous feedback loops from farmers to core stakeholders (F1 in Fig. 3).

Main supporting actors, such as traders, transporters, and processors, play a pivotal role in the FSC. These actors provide market access, inputs, and transportation services essential for smallholder farmers. However, the relationship is often exploitative, leaving farmers at a disadvantage. Therefore, policy guidelines (C2 in Fig. 3) are necessary to regulate these interactions and ensure fair benefits for all parties. Feedback loops (F2 in Fig. 3) enable continuous refinement of these guidelines to address emerging challenges.

We propose that the main supporting actors should also include financiers, NGOs, external investors etc. who contribute to the FSC activities through direct funding, interventions, and investments. However, their support must align with national priorities and focus on addressing FSC weaknesses, particularly those affecting smallholder farmers. Regulatory guidelines (C3 in Fig. 3) can help align these efforts, and feedback mechanisms (F3 in Fig. 3) can ensure interventions meet the farmers' needs.

Considering these modifications, the framework becomes as presented in Fig. 3. The proposed framework supports both vertical and horizontal collaborations. Vertical collaborations occur among diverse stakeholders across the FSC, such as farmers, government agencies, and traders, while horizontal collaborations involve stakeholders within the same category, such as farmer or trader associations. These collaborative structures promote inclusivity, reduce fragmentation, and improve coordination in addressing PHL.

Conclusion

Our findings align with existing research on the causes of post-harvest loss in developing countries (Abualtaher and Bar 2020; Bhattacharya and Fayezi 2021; Bradford et al. 2020; Godfray et al. 2010; Kasso and Bekele 2018; Kitinoja and Kader 2015; Verghese et al. 2013). Our approach differs from previous studies in identifying which stakeholders

should play the leading "core" role and which should act as supporting actors in addressing post-harvest loss. Furthermore, our categorization of horizontal and vertical collaborations is based on the roles played by stakeholders. Horizontal collaborations involve stakeholders with similar roles within the food supply chain, while vertical collaborations connect stakeholders with diverse roles. To address these issues, our proposed framework emphasizes facilitating collaborative conditions between smallholder farmers and core stakeholders (C1), core stakeholders and supporting actors (C2), and smallholder farmers and supporting actors (C3). These conditions, guided by clear policies, aim to align stakeholder efforts and promote effective collaborations. By adopting this framework and implementing policies to regulate and facilitate these collaborative conditions, developing countries can significantly reduce post-harvest loss. Moreover, the framework fosters the creation of stronger, more resilient food supply chains that enhance food security, improve smallholder farmers' incomes, and promote sustainable agricultural development.

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Author contributions
FI, EP, DM and SK conceived the study. FI collected the data and performed the preliminary analysis. EP, DM and SK supervised the data collection and analysis. FI wrote the paper. EP, DM and SK critically revised and approved the final version of the paper and contributed to the scientific content of the paper. All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon request.

Declarations

Ethics approval and consent to participate
All ethical clearance and consent of the participants were considered.

Competing interests
None of the authors have any competing interests in the manuscript.

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References

Abualtaher M, Bar ES (2020) Systems engineering approach to food loss reduction in norwegian farmed salmon post-harvest processing. Systems 8(4):13
Affognon H, Mutungi C, Sanginga P, Borgemeister C (2015) Unpacking postharvest losses in sub-saharan africa: a meta-analysis. World Dev 66:49–68. https://doi.org/10.1016/J.WORLDDEV.2014.08.002
AUC, T. A. U. C. (2018) Post-harvest loss management strategy (Issue August)
Barratt M (2004) Understanding the meaning of collaboration in the supply chain. Supply Chain Manag 9(1):30–42. https://doi.org/10.1108/13598540410517566
Bhattacharya A, Fayezi S (2021) Ameliorating food loss and waste in the supply chain through multi-stakeholder collaboration. Ind Mark Manag 93:328–343. https://doi.org/10.1016/J.INDMARMAN.2021.01.009
Bitzer VC (2011) Partnering for change in chains: on the capacity of partnerships to promote sustainable change in global agricultural commodity chains. Gildeprint Drukkerijen
Bradford KJ, Dahal P, Van Asbrouck J, Kunusoth K, Bello P, Thompson J, Wu F (2020) The dry chain: reducing postharvest losses and improving food safety in humid climates. In: Food industry wastes. Academic Press, pp 375–389
Bustos CA, Moors EHM (2018) Reducing post-harvest food losses through innovative collaboration. J Clean Prod. https://doi.org/10.1016/j.jclepro.2018.06.187

Caldeira C, De Laurentiis V, Corrado S, van Holsteijn F, Sala S (2019) Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. Resour Conserv Recycl 149:479–488
Cao M, Zhang Q (2011) Supply chain collaboration: Impact on collaborative advantage and firm performance. J Oper Manag 29(3):163–180. https://doi.org/10.1016/j.jom.2010.12.008
Chegere MJ, Lokina R, Mwakaje AG (2020) The impact of hermetic storage bag supply and training on food security in Tanzania. Food Secur 12(6):1299–1316. https://doi.org/10.1007/s12571-020-01052-9
Dania WAP, Xing K, Amer Y (2018) Collaboration behavioural factors for sustainable agri-food supply chains: a systematic review. J Clean Prod 186:851–864. https://doi.org/10.1016/j.jclepro.2018.03.148
Daszkiewicz T (2022) Food production in the context of global developmental challenges. Agriculture 12(6):832. https://doi.org/10.3390/agriculture12060832
de Putter H, Van Koesveld MJ, De Visser CLM (2007) Overview of the vegetable sector in Tanzania (No. 1). Wageningen UR
Downs TJ (2007) A systematic integrated approach for crafting poverty reduction and sustainable development projects. In: Natural resources forum, vol 31, No. 1. Blackwell Publishing Ltd., Oxford, UK, pp 35–50. https://doi.org/10.1111/j.1477-8947.2007.00129.x
Drost S, Van Wijk J, Mandefro F (2012) Key conditions for successful value chain partnerships: a multiple case study in Ethiopia Working Paper Series. www.partnershipsresourcecentre.org
Filimonau V, Ermolaev V (2021) Mitigation of food loss and waste in primary production of a transition economy via stakeholder collaboration: a perspective of independent farmers in Russia. Sustain Prod Consumption 28:359–370. https://doi.org/10.1016/J.SPC.2021.06.002
Godfray HC, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327(5967):812-818.
Gomez MI, Meemken E, Verteramo Chiu LJ (2020) Agricultural value chains and social and environmental impacts: trends, challenges, and policy options. In Agricultural value chains and social and environmental impacts: Trends, challenges, and policy options. FAO. https://doi.org/10.4060/cb0715en
Gustavsson J (2011) Global food losses and food waste. https://www.semanticscholar.org/paper/64d8c334b5bf8801f95395973e0fcdb7e3aab2da
Huxham C, Vangen S (2013) Managing to collaborate: the theory and practice of collaborative advantage. Routledge. https://doi.org/10.4324/9780203010167
Joensuu K, Hartikainen H, Karppinen S, Jaakkonen AK, Kuoppa-aho M (2021) Developing the collection of statistical food waste data on the primary production of fruit and vegetables. Environ Sci Pollut Res 28(19):24618–24627. https://doi.org/10.1007/s11356-020-09908-5
Kaminski J, Christiaensen L (2014) Post-harvest loss in sub-Saharan Africa—what do farmers say? Glob Food Sec 3(3–4):149–158. https://doi.org/10.1016/j.gfs.2014.10.002
Kasso M, Bekele A (2018) Post-harvest loss and quality deterioration of horticultural crops in Dire Dawa Region, Ethiopia. J Saudi Soc Agric Sci 17(1):88–96
Kitinoja L, Kader AA (2015) Measuring postharvest losses of fresh fruits and vegetables in developing countries. PEF White Pap 15:26
Kitinoja L, Saran S, Roy SK, Kader AA (2011) Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy. J Sci Food Agric 91(4):597–603. https://doi.org/10.1002/jsfa.4295
Kitinoja L (2013) Use of cold chains for reducing food losses in developing countries. Population, 6(1.23). www.iifir.org
Kumar D, Kalita P (2017) Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods 6(1):8. https://doi.org/10.3390/foods6010008
León-Bravo V, Caniato F, Caridi M, Johnsen T (2017) Collaboration for sustainability in the food supply chain: a multi-stage study in Italy. Sustainability. https://doi.org/10.3390/su9071253
Maxwell JA (2013) Qualitative research design: an interactive approach: an interactive approach. Sage
Midgley G (2007) Towards a new framework for evaluating systemic and participative methods. In: Proceedings of the 51st annual meeting of the ISSS-2007, Tokyo, Japan
Mihyo PB (2019) Agricultural policy and poverty reduction in Tanzania. Transportation, 46(77)
Mitchell RK, Agle BR, Wood DJ (1997) Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts. Acad of Manag Rev 22(4):853–886
Mutayoba V, Ngaruko D (2018) Assessing tomato farming and marketing among smallholders in high potential agricultural areas of Tanzania. Int J Econ Commerce Manag. VI. http://ijecm.co.uk/
Mwatawala HW, Mponji R, Sesela MF (2019) Factors influencing profitability of small-scale tomato (lycopersicon esculentum) production in Mvomero District, Tanzania. Int J Progress Sci Technol 14(1):114–121
Njume CA, Ngosong C, Krah CY, Mardjan S (2020) Tomato food value chain: managing postharvest losses in Cameroon. IOP Conf Ser Earth Environ Sci. https://doi.org/10.1088/1755-1315/542/1/012021
Oluwole O, Ibidapo O, Arowosola T, Raji F, Zandonadi RP, Alasqah I, Lho LH, Han H, Raposo A (2023) Sustainable transformation agenda for enhanced global food and nutrition security: a narrative review. Front Nutr. https://doi.org/10.3389/fnut.2023.1226538
Ombaeli S, Mtui H, Luambano N, Kashando B, Khursheed S, Sathyan T (2022) Tomato production in Mvomero district. J Curr Opin Crop Sci. 3(4)
Parfitt J, Barthel M, Macnaughton S (2010) Food waste within food supply chains: quantification and potential for change to 2050. Philosoph Trans R Soc b Biol Sci 365:3065–3081. https://doi.org/10.1098/rstb.2010.0126
Raut RD, Gardas BB, Kharat M, Narkhede B (2018) Modeling the drivers of post-harvest losses: MCDM approach. Comput Electron Agric 154:426–433. https://doi.org/10.1016/j.compag.2018.09.035
Ravitch SM, Riggan M (2016) Reason & rigor: How conceptual frameworks guide research. Sage Publications
Rutta EW (2022) Understanding barriers impeding the deployment of solar-powered cold storage technologies for post-harvest tomato losses reduction: insights from small-scale farmers in Tanzania. Front Sustain Food Syst. https://doi.org/10.3389/fsufs.2022.990528
Sasson A (2012) Food security for Africa: an urgent global challenge. Agric Food Secur 1(1):2. https://doi.org/10.1186/2048-7010-1-2

Sheahan M, Barrett CB (2017) Food loss and waste in Sub-Saharan Africa: a critical review. Food Policy 70:1–12. https://doi.org/10.1016/j.foodpol.2017.03.012
Simatupang TM, Sridharan R (2005) The collaboration index: a measure for supply chain collaboration. Int J Phys Distrib Logist Manag 35(1):44–62. https://doi.org/10.1108/09600030510577421
Surucu-Balci E, Tuna O (2021) Investigating logistics-related food loss drivers: a study on fresh fruit and vegetable supply chain. J Clean Prod 318:128561. https://doi.org/10.1016/J.JCLEPRO.2021.128561
Trienekens JH (2011) Agricultural value chains in developing countries a framework for analysis. Int Food Agribus Manag Rev. 14(2)
Ugonna C, Jolaoso M, Onwualu A (2015) Tomato value chain in Nigeria: issues, challenges and strategies. J Sci Res Rep 7(7):501–515. https://doi.org/10.9734/jsrr/2015/16921
URT (2012) REGIONAL REPORT: Iringa Region. In National Sample Census of Agriculture 2007/8: Volume: Vol. Vk: Region
URT (2016) 2016/17 Annual Agriculture Sample Survey: Initial Report
URT (2019) National Postharvest Management Strategy
URT (2022) Morogoro region social-economic profile
Verghese K, Lewis H, Lockrey S, Williams H (2013) The role of packaging in minimising food waste in the supply chain of the future : Prepared for: CHEP Australia
van Wagenberg C, Oudendag D, Dijkxhoorn Y, Plaisier C, Groot J, Kok M (2019) How do trust, social norms and risk attitudes influence sustained adoption of interventions to reduce post-harvest losses? Application of an agent-based model to the tomato value chain in Nigeria
Zacharia ZG, Nix NW, Lusch RF (2011) Capabilities that enhance outcomes of an episodic supply chain collaboration. J Oper Manag 29(6):591–603. https://doi.org/10.1016/j.jom.2011.02.001

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