



Conceptual Analysis of Food Security through Post-Harvest Loss Mitigation in Developing Nations

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ABSTRACT

This study examines the concept of food security in developing countries, particularly India, from the perspective of post-harvest loss (PHL) reduction. Food security remains a serious challenge amid rapid global population growth and limited resources. Simply increasing production is not enough, as 25-40% of food is lost after harvest during storage, transportation, processing, and marketing. This loss directly impacts availability, accessibility, utilization, and sustainability all four dimensions of food security. The study presents definitions, measurement methods, and a conceptual analysis of the interrelationships between food security and post-harvest losses. Globally, approximately one-third of food production is lost annually, negatively impacting nutrition, income, and social stability in developing countries. In India, lack of storage infrastructure, technological backwardness, market disorganization, climate risks, and the limitations of smallholder farmers are key factors. Technological innovation, cold storage, improved transportation; market reforms, policy support, and community participation have been identified as effective strategies for PHL mitigation. Examples from Andhra Pradesh, Karnataka, and Tamil Nadu demonstrate that appropriate policy, infrastructure, and training can significantly reduce losses. In conclusion, reducing post-harvest losses is a powerful tool for increasing food availability, ensuring price stability, and strengthening rural livelihoods.

Keywords: Food Security, Post-Harvest Loss, Developing Nations, Supply Chain Management, Food Availability, Sustainable Agriculture.

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1. Introduction

Food security remains a pressing global challenge, particularly for developing nations. In the past eighty years, the world population has increased fourfold, and food production must quadruple to maintain the same per capita consumption level (Kumar et al., 2014). The

Heavily Indebted Poor Countries (HIPC) Initiative highlights food security as an agenda priority, noting that vulnerability to food supply fluctuation persists despite surpluses in national production. India exemplifies a country grappling with food insecurity across availability, access, utilization, and stability dimensions. Production strategies dominate food security discussions in India, yet system bottlenecks especially post-harvest losses (PHL) at farm and market levels undermine security and compel attention.

This research adopts a conceptual lens focused on PHL mitigation to enhance food security in developing nations and India. The conceptual analysis delineates food security, PHL, and mitigation definitions, frameworks, and indicators and explicates the interrelations among availability, access, utilization, and stability. Food security indicators include per capita calorie and protein intake, quantity per capita availability, and hunger indices. PHL measures encompass quantity (total, net, and economic), stages (production—including harvest, handling, storage, and processing), and efficiency. The analysis observes a strong link between mitigation and access, utilization, and stability yet acknowledges uneven integration of PHL within availability and interconnectedness across all five aspects.

2. Theoretical Foundations of Food Security

The theoretical foundations of food security have evolved significantly since its conceptualization. Coined against the backdrop of the food crisis in the mid-1970s to advocate for food availability and supplies, the term gained traction in the 1980s along with renewed focus on poverty and entitlement and subsequently adopted a multi-dimensional perspective encompassing availability, access, utilization, and stability. Availability and stability remain crucial for developing nations where vulnerability to food insecurity is often linked to underdevelopment and rampant post-harvest loss (PHL) (Kumar et al., 2014).

International policy initiatives have prioritised PHL in food security discussions. The UN General Assembly proclaimed 2016 the International Year of the Pulses, spotlighting its mitigation as key to enhancing food security and nutrition. Indian Prime Minister Narendra Modi, during the opening ceremony of the International Conference on Agriculture, Food Security, and Nutrition in 2015, affirmed that reducing PHL is pivotal for increasing the availability of food and ensuring that the entire population is unfailingly provided.

3. Post-Harvest Loss: Definitions, Dimensions, and Measurement

Post-harvest losses (PHL) encompass the physical, qualitative, and economic deterioration of goods between production and consumption. Various causes generate PHL throughout value chains, even in well-functioning markets (Brockamp, 2016). Globally, about one-third of food produced for human consumption—approximately 3 billion tonnes annually is lost or wasted, with developing regions disproportionately affected. PHL mitigation offers significant potential for reducing food insecurity, enhancing nutrition, and improving smallholders' incomes and resilience (Affognon et al., 2015). For example, in the African post-harvest system, annual food loss after harvest is estimated at USD 4 billion for grains alone, exceeding the value of total food aid received over the past decade and equating to the

caloric needs of 48 million people. In India, PHL reductions could liberate food equivalent to 192 million tonnes of wheat annually.

Food loss refers to the quantitative or qualitative loss of food measurable in physical quantities, value, or nutritional quality. Post-harvest loss pertains specifically to the food loss at the value chain stages following the harvest of crops. PHL can occur simultaneously with the realization of quantity or quality gains on the same or another crop. The distinction between food loss and food waste lies primarily in the source where the loss or waste occurs. Although both terms are often used interchangeably, loss typically occurs at earlier stages of the supply chain and waste at later stages. For example, reduction of unmarketable food in wholesale markets is still referred to food loss, since it occurs before reaching the consumers.

4. Causes of Post-Harvest Loss in Developing Nations

In developing nations, post-harvest loss (PHL) occurs when, after harvest, food crops deteriorate or are wasted altogether before they reach their intended destination or consumer (van Gogh & Aramyan, 2014). Such losses are estimated to be between 25 and 40% of total production. Variation exists across crop types, value chains, countries, and regions. PHL can be considerably reduced through low-cost, simple, and technologically appropriate interventions that are appropriate to local conditions of climate, infrastructure quality, resources, and culture. Yet the magnitude of PHL remains substantial, and awareness of the problem is increasing.

Careful institutional, infrastructural, policy, and technical analysis is therefore warranted as key insights can be garnered from analyzing the myriad causes of PHL across a range of development contexts and crops. Even within the broad field of PHL, the principal variants of analysis include clear distinctions according to the nature of the cause within value-adding perspectives, or variations that understand causality more closely as a function of the social, economic, and political environment. Nonetheless, although PHL always exists in relation to a cycle of supply and demand, the overwhelming preponderance of research focusses only the supply side of the chain, and, where significant losses can occur, identification of the factors governing demand. As a consequence, PHL reductions of over thirty percent can be registered and demand-side approaches be deemed appropriate in some instances without addressing the wide-ranging supply constraints on which demand can attempt to build (van Gogh & Aramyan, 2014).

A variety of causal configurations operate within developing nations, all of which interact in differing combinations depending on the precise situation. Among these interrelated factors, technical, infrastructural, logistical, institutional, and climatic, for example, are fundamental to PHL and require consideration. Gender constraints, the predominance of smallholder farmers, unstable international and local aggregate prices, and rising global demand for certain commodities represent additional drivers of PHL. Moreover,

climate risk and seasonal variability shape the supply available for sale after harvest and govern the magnitude of PHL across a crop year.

5. Post-Harvest Loss Mitigation Strategies

Post-harvest food losses are defined as the reduction of food availability during the post-harvest stage after food has been harvested but before it reaches the consumer. They are a highly prevalent issue in developing nations and are caused by many factors including inadequate harvest and post-harvest management practices, high ambient temperature and humidity, lack of processing and preservation techniques, inadequate storage and transport facilities, and poor marketing systems. Depending on the crop, materials and methods used, season, time lag between harvest and sale, and market distances, losses occur in various forms physical, monetary, and nutritional at different stages of the supply chain and are greatly affected by socio-economic and climatic conditions. Post-harvest losses can occur throughout the entire post-harvest supply chain including the drying, handling, storage, transport, processing, and marketing stages but their occurrence and percentage may vary by crop type. Improvement of simple and low-cost structures and equipment for harvesting, drying, storage, transport, and processing; formulation and dissemination of safe and effective post-harvest handling, drying, storage, conservation, transport, and marketing systems; and better management of markets to provide timely price signals to producers enables efficient handling of crops after harvesting and helps to avoid post-harvest losses. (Affognon et al., 2015)

5.1. Technological Interventions

Technological interventions aimed at storage, packaging, drying, and processing operations offer great promise for reducing food losses, particularly in low-resource contexts (Parwez, 2013). However, experience with many technologies to mitigate post-harvest loss has been disappointing in developing countries, especially for low-value staples such as grains. Well-intentioned but sub-optimal designs, lack of integration with local practices and knowledge, poor after-sales training and support, and ineffective promotion of new technologies can diminish the chances of success (Mutungi & Affognon, 2013). Further, the multiplicity of locally specific conditions encountered—including agro-ecological factors, practices, products, market access, cultural preferences, and social variables—poses additional challenges. Existing tools target food safety, quality control, short-term preservation, or fresh aggregation, with technologies emphasizing structural or electric approaches yet needing prior assessment to reduce post-harvest loss efficiently. As a result, operational criteria encompassing these aspects can help identify appropriate candidate technologies, drawing upon the extensive range of potentially relevant innovations.

5.2. Infrastructure and Market Access

Despite food security being a pervasive development challenge for many developing countries, its extremely intricate nature renders it an exceedingly elusive concept (Parwez, 2013). Poverty alleviation, food climate change, food sovereignty and security, hunger, malnutrition and obesity, rural and urban issues, health and disease, sustainability, food

waste, land, water and water management, the food and agricultural market, livestock and fisheries management, food prices and food inflation, food quality, nutritional and safety guidelines, youth integration, country and area safety and governance, competitiveness and globalization, value chains, standards and quality problems, economic conditions and uncertainties, transition economies and political economies, technology management and technics, food aid, food purchasing, food security information and communication, food security in India, and future trends in global food security are evident in such a mismatch between the ultimate objective and undesirable food situations. Various internal and external forces may mould the food situation of a country like nutrient availability, affordability and consumption choice. Nonetheless, relevant policies are seldom adopted (van Gogh & Aramyan, 2014).

Political crises occur at all levels and is an impediment in the way of food security. A landlocked country like Nepal appears at a higher risk although it is impossible to reach complete food security, but a lot can still be done to facilitate food security.

5.3. Policy Instruments and Governance

Post-harvest losses of agricultural produce contribute significantly to food insecurity in developing countries. Various kinds of physical, economic, and quality-related losses are incurred in different stages of the food value chain, leading to massive wastage of food. Mitigating post-harvest losses could be a potential strategy to enhance the availability, access, and affordability of food, thereby addressing food-security issues. An analysis of the policy instruments and governance arrangements that enable post-harvest-loss mitigation in India can provide critical insights.

Post-harvest-loss mitigation has been emphasized in the policy discourse of India. Recognizing the importance of post-harvest-loss mitigation, a report on the National Agriculture Policy has mandated a multi-pronged strategy for creating an efficient food supply chain across-the-board (Parwez, 2013). Initiatives for promoting post-harvest-loss mitigation have been instituted in the Eleventh and Twelfth Five-Year Plans and are included in the current National Policy for Farmers. Despite the formal recognition of post-harvest-loss mitigation, public-private partnerships for reducing post-harvest losses have garnered insufficient attention. An understanding of the policy instruments, governance frameworks, and public-private partnerships that facilitate post-harvest-loss reduction can inform the broader debate on India's food security.

5.4. Community and Farmer-Centric Approaches

Post-harvest losses are experienced across various stages and may take on physical, economic, or quality-related dimensions. Distinguishing between preventable losses that can be effectively curtailed through suitable interventions and unavoidable losses that can only be reduced in relation to inherent, often location-specific uncertainty facilitates a better understanding of the cost-benefit expectations associated with mitigation efforts. Diverse

measurement approaches have been applied across the developing world—ranging from statistical surveys, on-farm assessments, and remote-sensing methods to warehouse audits—but none of the existing tools offers a universal solution, and those included in the PHL framework (Parwez, 2015) presently lack direct application in India.

PHL remains a significant contributor to food insecurity among developing countries, and India is no exception. Within developing countries, physical PHL, mainly occurring at the production, handling, and storage stages, is typically highest, accounting for an estimated 20–30 percent of total post-harvest activity (Lopez-Ridaura et al., 2018). Large-value PHL, which may involve a substantial percentage of the total economic activity and profit of some value chains, is also notable (Friedrichsen et al., 2018). Other developing economies face similar PHL magnitudes, and time series or comparable cross-country data document substantial positive welfare impacts arising from verified PHL reduction interventions, with mitigation benefits in some instances exceeding the cost of further production increases (Parwez, 2015).

Programmes targeting marginalised smallholder farmers, recurrently identified as India's most vulnerable segment, demonstrate corresponding transfers and welfare enhancements of considerable significance. Alongside the sizeable PHL estimate, a wealth of documented case studies describes technological options extending across five different operations—namely, storage, drying, pre-conditioning, packing, and processing—sufficient to establish a solid foundation for country-specific exposition and a more general convergence towards crop and country analytical work.

6. Economic and Social Implications of Post-Harvest Loss Reduction

Post-harvest loss (PHL) reduction holds key economic and social implications for developing nations, influencing cost savings, risk exposure, food affordability, livelihood creation, rural development, and equity (Affognon et al., 2015). Lowering PHL diminishes the operating costs of production, storage, and distribution and consequently reduces wholesale and retail market prices. Investments in PHL mitigation gear towards savings on inputs and services that remain constant despite fluctuations in output. Empirical evidence suggests that food prices decline as PHL mitigation occurs, enhancing real-world affordability. In turn, reduced food-flavor risks encourage favourable consumption patterns. Several technologies also improve food processing, preservation, and pre-harvest yield, potentially increasing food availability.

Mitigation enables investments in other community and national priorities and contributes directly to job generation and employment creation in post-harvest management. PHL reduction supports rural development by encouraging crop diversifications, stimulating effort in crops and varieties, and attracting investments in related activities (processing, community roads, and accessible market information). The equitable dimension of PHL reduction also emerges in efforts with a particular focus on women, youth, smallholders, or resource-poor. Affognon et al. (2015) exhibit that enabling environments from 30 developing

nations adopting PHL-reducing coupling regulations contribute to employment opportunities and equitable income distribution.

7. Empirical Evidence from Developing Nations with Emphasis on India

Implementing food security is imperative to address hunger challenges. In this regard, PHL mitigation can be an effective way to ensure food security. In developing nations, including India, an enormous amount of food is lost in post-harvest activities. Mitigation of these losses directly impacts availability and access. Many studies assess PHL and its mitigation, but evidence of the impact of PHL mitigation measures on food security is scant. Systematic empirical evidence regarding PHL and its mitigation measures in developing countries, especially India, remains sparse. Moreover, even where such evidence exists, a significant time lag often hampers its applicability for further research. When PHL and their mitigation measures in developing nations have been extensively reviewed, it reveals how PHL can act as a proxy to assess food security and defines the process through which decisions can be made to scrutinize various modelling outcomes.

Quantitative assessment of PHL across 125 developing countries estimates how PHL mitigation affects welfare, availability, and access, effectively laying out the international scenario. Since 1970 more than 175 PHL mitigation initiatives in India have been documented, but detailed programme descriptions, evaluation evidence, and relevant outcome information are harder to procure. Nevertheless, a comparative analysis demonstrates that the role played by mitigation in food security remains vital when PHL are taken into consideration, enabling selection of countries representative of diverse contexts and facilitating identification of design principles common across nations. Even 25 mitigating actions remain unidentified and PHL continue to receive limited attention, a survey of 85% of Indian institutions involved in PHL reduction reveals an urgent need to deepen understanding of the factors shaping ongoing endeavours and the design of supplementary measures to fill outstanding gaps.

8. Case Studies: Successful Models of Post-Harvest Management in India

Post-harvest loss (PHL) is critical to food security in India. Lessons from successful interventions may inform replicable solutions. Criminal law reform in Andhra Pradesh and the District Supply Chain Management Project (DSCMP) in Karnataka exemplify statewide programs that have yielded measurable PHL reduction. The Andhra Pradesh initiative streamlines licensing to facilitate agricultural marketing in line with the 2017 Agricultural Marketing Reform. Information Communication Technology (ICT) has raised awareness about food safety and best practices, enabling collective selling through farmers' organisations, and fostering time and cost savings. The pilot phase in four districts (2019–2021) recorded financial gains and reduced wastage. Similarly, the DSCMP assists smallholders in managing the marketing process following harvest, recognised as a main loss point. Since 2018, this programme has improved marketing intelligence, produced farmer

appraisals, and linked producers to multiple buyers. Additional measures target storage and mechanisation, support for schemes, and developing a GIS-based tracking system for inputs, harvest, and revenues; these have collectively reduced PHL. Positive outcomes indicate wider applicability beyond their original contexts.

In parallel, between 2015 and 2017, Tamil Nadu's collective-purchase programme expanded local dairy farmers' access to chilling units, collectively owned, monitored, and operated via self-help group (SHG)/non-governmental organisation (NGO) partnerships. Almost 550,000 units serve 30 per cent of producers. Pilot sites demonstrated a doubling of monthly income to ₹6,000 per SHG over the previous 5–10-year timeframe. PHL reduction has accompanied enhanced profits. Facilitating access to oft-uneconomic chilling units serves as the prime intervention; complementary investments in electronic weighing, chemical testing, and transport are advisable yet less critical.

Common design principles incorporate stakeholder proximity, enabling local-selection discretion; cross-entity collaboration, fostering process improvement; and participatory gallery walks, jointly assessing outcomes and strategies, supplemented by both written and visual documentation.

Effective interventions further depend on second-order conditions. Andhra Pradesh's programme reveals the crucial role of a conducive policy environment. All involved constituencies must concurrently back the initiative, a factor when replicating this intervention in other Indian jurisdictions. Moreover, supplementary support should encompass feasible, impactful interventions that complement existing measures. The time elapsed since the aforementioned state initiatives points to demand for additional second-order options. (Parwez, 2013)

9. Challenges, Gaps, and Policy Priorities

Adequate attention to post-harvest loss (PHL) highlights many challenges, gaps, and policy priorities that require further exploration to enhance the contribution of PHL mitigation to improved food security in developing nations, especially India.

While significant literature addresses food security, PHL, and a wide range of related topics, systematic efforts devoted to PHL in developing contexts remain scarce. Limited empirical assessments specifically examining PHL across developing countries underscore the need for a broader analysis that elucidates the theoretical underpinnings of food security and PHL, explores the causes and mitigation of PHL, and emphasizes the economic and social implications of PHL reduction. Even in the expanding body of India-focused studies, attention to PHL and its relationship to food security is notably underrepresented.

Despite growing recognition of the critical need to strengthen the food security situation of the rural poor in India, suitable data, tools, and frameworks needed to support effective prioritization remain highly limited. Enhancing the PHL theme in the food security agenda can help address a number of existing gaps and challenges.

Considerable gaps persist in the availability, quality, and disaggregation of pertinent data on food security, infrastructure, and other interlinked elements. Further investment is needed to collect, compile, and disseminate comprehensive statistical information on the volume, value, and determinants of PHL across different value chains, provinces, and socioeconomic segments. Developing standardized indicators to evaluate the status and evolution of PHL over time can enhance the consistency and tractability of analysis. Methodological advances are also warranted to strengthen the soundness of PHL estimation techniques, tackle complementary information requirements, and distinguish PHL from other correlated but conceptually distinct phenomena.

India's extensive history of post-harvest measures, progressive policies and programs, active investment by diverse stakeholders, and targeted public interventions to mitigate PHL provide rich analytical insights. A range of priority avenues have emerged for further policy reform, investment, and complementary action aimed at optimizing the PHL focus within the broader food security agenda and enhancing the resulting food security impact (Parwez, 2013) ; (Kumar et al., 2014).

10. Methodological Considerations for Future Research

Future research on post-harvest loss (PHL) mitigation in developing countries can benefit from several methodological considerations comprising data collection, causal inference, measurement standardization, and cross-national comparison. Implementing the framework introduced here requires improving data availability and collection methods, establishing causal links between mitigation and food-security dimensions, harmonizing metric definitions and measurement protocols, and enabling comparative analysis across developing countries such as India.

PHL-mitigation research faces considerable data constraints owing to a lack of systematic collation and synthesis. Without such datasets, drawing normative or policy conclusions remains hindered. To support inter-country comparisons and the identification of globally relevant strategies, systematic data-entry and collation—or the development of freely available databases should cover country-specific PHL estimates and mitigation impacts. The baselines for 1–6a PHL data can be referenced from the technical sections of the Andhra Pradesh, Punjab, and Tamil Nadu state cases. Additional country coverage should complement Intergovernmental Panel on Climate Change (IPCC) climate change and agricultural information systems (AgMIP) drought data, enabling quantitative estimation and analysis of PHL under climate-induced stress, thereby generating globally relevant insights.

11. Conclusion

Agencies striving to achieve food security in developing nations face a significant challenge posed by post-harvest loss (PHL): many thousands of kilocalories of food energy produced (and much well-intentioned effort) go to waste because of poor handling. These

losses are broadly correlated, across nations, with economic development, yet the reasons for this correlation are not clear. PHL mitigation defined as any action that reduces the total quantity of food lost thus becomes a compelling policy priority, especially in India, where myriad initiatives are underway.

The conceptual framework presented here seeks to inform discourse on PHL and nourish further research devoted to the subject. It synthesizes the relevant scholarship and captures the perspectives of multiple disciplines and branches of knowledge, illuminating the concepts of food security, post-harvest loss, and mitigation. Each concept is defined and contextualized in accordance with its theoretical underpinnings, accompanied by a mapping of causal pathways and systemic dependencies. Key institutions in the Indian landscape are then integrated into the analysis. A series of several basic capabilities for reducing PHL is identified. Each of these capabilities can be pursued through one or more distinct means—technologies, infrastructure improvements, governance frameworks, and collective action—whose relative importance varies according to local circumstances.

Conflict of Interests

None.

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