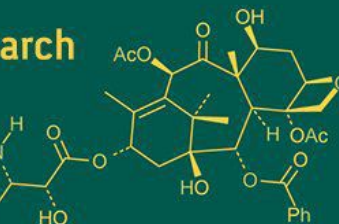
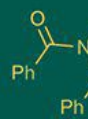
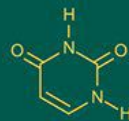


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Extension strategies to promote post-harvest management and value addition: A review

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Abstract

Post-harvest losses among agricultural commodities remain an important challenge to food security, farmers' income, and agricultural productivity as a whole. Effective post-harvest management and value addition are critical to reduce losses, retain quality, and improve marketability. Agricultural extension services can be crucial in knowledge dissemination, capacity building, and promoting innovation for stakeholders, including small and marginal farmers. This review critically analyzes different extension approaches used to enhance post-harvest handling, storage, processing, packaging, and marketing of farm produce. Important strategies like farmer field schools, ICT-based advisory services, participatory training, capacity building programs, public-private partnerships, and policy advocacy are elaborated. The review also focuses on the involvement of women and youth in post-harvest management and identifies successful case studies from India and other developing nations. It concludes with suggestions for strengthening extension frameworks to support sustainable value addition and post-harvest systems.

Keywords: Post-harvest management, value addition, agricultural extension, ICT, farmer training, capacity building, post-harvest losses, marketing, agro-processing, rural development

Introduction

Post-harvest management is the total range of operations and practices that are performed following the harvest of crops, such as cleaning, sorting, grading, drying, packaging, storage, transportation, and processing (Adom, 2018) [3]. These operations are necessary to ensure the quality and safety of farm produce, minimize quantitative and qualitative losses, and provide food throughout the year (Onwude, *et al.*, 2020) [49]. Effective post-harvest management enhances the shelf-life, visual appeal, nutritional value, and marketability of crops, thereby making a direct contribution to food security and income stability (Osei-Kwarteng, *et al.*, 2024) [50].

The horticulture industry has huge scope for productive wasteland development in a systematic and planned manner (Lalpekhluva, *et al.*, 2024) [36]. In contrast to traditional food crops, horticultural crops require lesser water, create higher employment opportunities, and are more eco-friendly (Tadesse, *et al.*, 2024) [72]. From the nutritional security perspective, fruits and vegetables have a huge value addition scope (Osei-Kwarteng, and Ogwu, 2024) [51]. It not only enhances their marketability but also adds significantly to foreign exchange (Bappah, and Adejoh 2024) [7]. Therefore, horticultural crops are not just essential agricultural products but also a prominent commercial commodity with increasing global market opportunities (Adewoyin, 2023) [2].

Despite significant improvements in agricultural production over recent decades, post-harvest losses remain alarmingly high, particularly in developing nations like India (Kiaya, 2014) [33]. Studies indicate that approximately 30-40% of perishable commodities such as fruits and vegetables are lost annually due to inefficient post-harvest systems (Rajapaksha, *et al.*, 2015) [57]. These losses are incurred at different stages-during harvesting, handling, storage, processing, and marketing and are primarily due to inadequate infrastructure, lack of knowledge, inferior packaging materials, and the absence of cold chain logistics (Kumar, and Kalita, 2017) [35]. This wastage not only means a loss of food but also causes financial losses to farmers and the country as a whole (Ishangulyyev, 2019) [27].

Table 1: Post-Harvest Technologies Influencing Shelf Life of Horticultural Commodities

S.No.	Post-Harvest Technology	Key Practices/Details
1	Harvesting Techniques	Timely and proper harvesting (right maturity stage) Use of sharp tools to avoid mechanical injury Gentle handling to avoid bruises/cuts
2	Pre-Cooling & Cooling Methods	Pre-cooling (immediate field heat removal) Hydro-cooling Forced-air cooling Vacuum cooling Ice cooling Cold storage
3	Curing	Used for onion, garlic, sweet potato Drying of outer layers to prevent microbial infection and moisture loss
4	Washing and Cleaning	Removal of soil, debris, and microbes Use of sanitizers (chlorinated or ozonated water)
5	Grading and Sorting	Based on size, shape, color, and maturity Reduces losses and improves market value
6	Packaging Technology	Protects produce during handling/transport Modified Atmosphere Packaging (MAP) Controlled Atmosphere Packaging (CAP) Use of trays, polybags
7	Waxing and Edible Coatings	Reduces respiration and water loss Slows down ripening and microbial spoilage
8	Storage Techniques	Cold storage (0°C to 10°C crop-specific) Controlled atmosphere storage Zero Energy Cool Chamber (ZECC)
9	Ripening Chambers	Use of ethylene gas/generators Avoids use of harmful ripening agents like calcium carbide
10	Radiation Treatment	Gamma irradiation for microbial and insect control Delays ripening and sprouting
11	Plant Growth Regulators (PGRs)	1-Methylcyclopropene (1-MCP): delays ripening Gibberellic acid (GA ₃): extends grape shelf life
12	Biotechnology & Nanotech	Bio-coatings, nano-packaging, bio-preservatives Enhances shelf life and produce safety
13	Transportation Management	Use of refrigerated vans, cushioned packaging, crates Minimizing transit time
14	Processing & Value Addition	Conversion into jams, pickles, juices, dehydrated products Increases shelf life and market opportunities

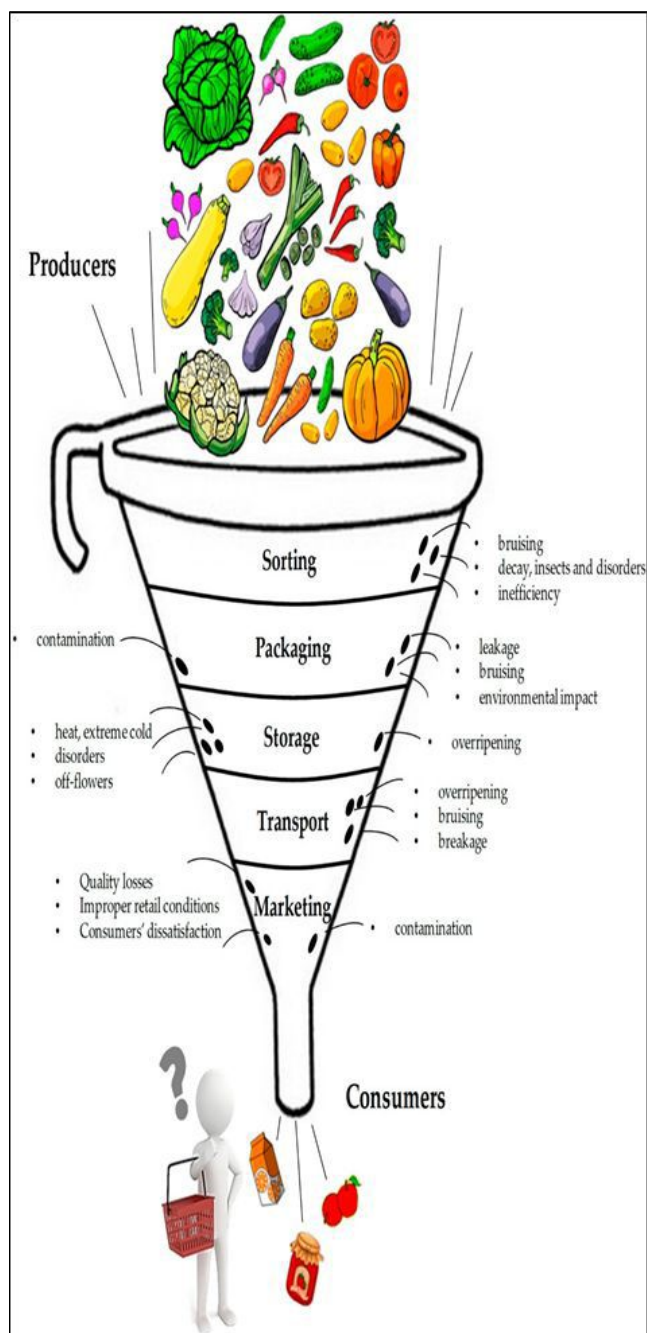
Here, value addition is a revolutionary step by increasing the economic value of raw farm products. This can be done through operations like minimal processing (e.g., cutting, drying, or freezing), advanced processing (e.g., production of jams, pickles, or juices), better packaging, branding, or promotion (Sharma, 2014) ^[62]. Value addition allows farmers and rural entrepreneurs to access niche and premium market segments, increase product shelf-life, decrease perishability, and get increased returns (Singh, *et al.*, 2025) ^[67]. In addition, it triggers the development of agro-based industries, promotes entrepreneurship, and creates rural employment especially among women and youth (Bolanle, *et al.*, 2022) ^[9].

Agricultural extension services are the major vehicles for promoting post-harvest management and value addition practices among farmers (Kamanda, 2022). They serve as a key link between research institutions, government departments, private players, and the farming community (Silamat, *et al.*, 2024) ^[64]. Extension agents impart knowledge and training in best practices, introduce new technologies, demonstrate better methods, and develop the capacity of farmers to adopt and maintain improved post-harvest and value-added operations (Fatty, 2019) ^[17]. Through participatory methods like farmer field schools, ICT platforms, and capacity-building programs, extension has a central role in reducing losses, enhancing incomes, and turning subsistence farming into a commercial enterprise (Kitinoja and Barrett, 2015) ^[34].

In the face of worldwide issues like climate change, population expansion, and dwindling natural resources, improving post-harvest systems and promoting value addition has never been more important. It not only provides effective use of resources but also complements national objectives of agricultural sustainability, rural development, and economic resilience.

Significance of Post-Harvest Operations and Value Addition: Minimization of Post-Harvest Losses

Post-harvest losses can vary between 20%-40% in fruits and vegetables in India, largely due to ineffective handling, inadequate storage facilities, and inefficient transport systems (Anand, and Barua, 2022) ^[5]. Not only are these losses diminishing the availability of healthy food for the consumer, but these losses also amount to financial losses for the farm community and the country (Negi, and Anand, 2017) ^[47]. Efficient post-harvesting management practices like field-level grading at the very first instance of picking, picking at the proper time, application of crates as a substitute to gunny bags, and establishing cold chain network facilities can drastically minimize such waste (Boxall, *et al.*, 2022) ^[11]. Extension methodologies encouraging training through these practices may assist farmers to implement improved procedures, thereby bringing about food safety and alleviation of pressure from natural resources due to optimal production utilization (Arowosegbe *et al.*, 2024) ^[6].



Source, (Palumbo *et al.*, 2022) ^[52]

Fig 1: Causes of postharvest losses along the supply chain. (Bourne, 1977) ^[10].

Table 2: Influence of Extension Methods on Post-Harvest Techniques in Horticulture

S.No.	Extension Method	Influence on Post-Harvest Techniques
1	Demonstration (Method & Result)	Shows practical use of post-harvest tools (e.g., cold storage, grading machines) Builds farmer confidence through visible results
2	Farmers' Training Programs	Enhances farmers' skills in handling, packaging, and storage Promotes awareness of value addition and shelf life extension
3	Field Visits & Exposure Tours	Facilitates learning from progressive farmers or agri-enterprises Encourages adoption of improved storage and processing units
4	On-Farm Trials (OFT)	Helps test new post-harvest practices in local conditions Promotes farmer participation and feedback-driven technology refinement
5	Front Line Demonstrations (FLD)	Promotes use of specific technologies like ZECC, MAP, or PGRs Encourages adoption through performance proof
6	Use of ICT Tools (Mobile Apps, Videos, SMS)	Disseminates timely information on harvest indicators, storage tips, and market prices Provides remote guidance for smallholders
7	Farmers' Field School (FFS)	Encourages group learning on handling perishables Engages farmers in identifying and solving post-harvest issues together
8	Mass Media (Radio, TV, Newspapers)	Raises broad awareness on scientific post-harvest practices Useful for reaching remote or illiterate farmers

9	Exhibitions and Krishi Melas	Showcases latest post-harvest machinery and packaging innovations Encourages tech adoption through live demonstrations
10	Participatory Rural Appraisal (PRA)	Helps understand local post-harvest issues and resource gaps Tailors extension advice to community-specific needs
11	Printed Literature (Leaflets, Posters, Manuals)	Reinforces learning with visual aids Serves as handy reference material for farmers
12	Agri-Clinics & Advisory Services	Offers expert advice on post-harvest diseases, storage temperature, or processing options Supports individual decision-making

Improving Shelf-Life and Food Safety

Post-harvest treatments including curing, cleaning, sorting, grading, waxing, packaging, and controlled atmosphere storage ensure the physical, chemical, and sensory attributes of the produce (Lalpekhlua *et al.*, 2024) ^[36]. It not only increases shelf-life but also food safety by reducing microbial load and contamination hazards (Teshome, *et al.*, 2022) ^[74]. For instance, applying low-temperature storage to perishable vegetables like tomatoes and leafy greens retards ripening and rot. Maintaining good hygiene during processing and implementing Good Handling Practices (GHP) and Hazard Analysis and Critical Control Points (HACCP) procedures also enhance the acceptability of produce in domestic and foreign markets (Nicola, *et al.*, 2022 and Ilyas, 2010) ^[26, 48].

Rural Employment and Entrepreneurship Generation

Post-harvest management and value addition generate substantial employment opportunities in rural regions (Swain, *et al.*, 2021) ^[71]. Small-scale operations like grading, sorting, packaging, and primary processing (e.g., sun drying, canning, pulping) can be grouped into cottage industries or self-help groups, especially women and rural youth (Maheshwari, and Nirgude, 2021) ^[37]. These operations not only offer alternative sources of income but also empower local communities and limit migration to urban centers (Mayer, 2003) ^[38]. Entrepreneurship in value-added items like jams, pickles, dehydrated vegetables, fruit drinks, or ready-to-eat foods also contributes to economic development and rural agro-based industry growth (Mole, 2018) ^[42].

Higher Farm Income and Market Competitiveness

Farmers who value-add are able to command improved prices for their produce (Napitupulu *et al.*, 2009) ^[45]. Rather than selling unprocessed or raw produce at slim margins, they are able to process, package, and brand their products to get access to higher-value marketplaces (McKinna, 2004) ^[39]. For instance, the farmer selling unprocessed turmeric will receive lesser income than that selling processed turmeric powder packaged in branded packets (Greenland *et al.*, 2023) ^[23]. Further, value addition creates market competitiveness in the form of product differentiation through quality, pack, and shelf-stability. This diversification reduces the risk of price risks in fresh produce markets and also ensures financial viability (Gage *et al.*, 2024) ^[20].

Food Processing Industries and Export Potential

Promotion: India's immense agricultural base offers a robust platform for the development of the food processing industry (Rais, *et al.*, 2013) ^[56]. Value addition accelerates this potential by offering semi-processed or finished goods to the processing industry (Pamwal, and Tata, 2019) ^[53]. Furthermore, value-added products such as fruit pulps, frozen vegetables, or ready-to-eat foods adhere to the

quality requirements for export in international markets (Kannaujia, *et al.*, 2019) ^[31]. Better packaging and labeling, conformity with food safety standards, and ensuring product consistency are very important for increasing export potential (Henson, and Jaffee, 2006) ^[24]. The development of such industries adds to national income, creates employment, and earns precious foreign exchange, while at the same time minimizing post-harvest losses (Kiaya, 2014) ^[33].

Extension Strategies for Post-Harvest Management and Value Addition: Farmer Field Schools (FFS)

Farmer Field Schools are experiential and discovery-oriented learning systems that involve groups of farmers in the company of trained facilitators (Fomba, 2009) ^[19]. Through season-long participation, farmers learn about live post-harvest management issues, carry out experimental trials, and test the effectiveness of new technologies in their own fields (Akuno, 2015) ^[4]. FFS training sessions can be tailored to illustrate the application of solar dryers in fruit and vegetable drying, hermetic storage bags minimizing insect attack and moisture entry, and low-cost packaging materials that extend shelf-life (Saha, *et al.*, 2024) ^[59]. Through this hands-on training, farmers gain confidence, and peer-to-peer learning takes place, leading to greater uptake of enhanced practices (Sutherland, *et al.*, 2024) ^[70].

Information and Communication Technology (ICT)

Extension service utilization through ICT has transformed the way information is conveyed (Ezeh Ann, 2013) ^[15]. Mobile phone-based applications, SMS, WhatsApp groups, call centers (such as Kisan Call Centres), and online platforms like Agri-Diksha, Kisan Suvidha, and e-NAM provide timely access to information on best harvesting windows, safe storage temperatures, post-harvest hygiene, and current market prices (Menon *et al.*, 2017) ^[40]. ICT also helps farmers to acquire knowledge about value-added products, packaging technology, and government schemes through videos, audio messages, and infographics, which are frequently in local languages (Setia *et al.*, 2024) ^[61]. This live, local, and low-cost access to specialist advice empowers farmers to make better-informed decisions and minimize post-harvest risk (Fiedler, 2020) ^[18].

Capacity Building and Skill Development

Equipping farmers and rural businesspeople with useful skills is the foundation of post-harvest extension (Kamanda, 2022). Training schemes conducted by Krishi Vigyan Kendras (KVKs), NGOs, agricultural colleges, and other institutions emphasize areas like cleaning and grading methods, preservation processes (e.g., pickling, jam making, dehydration), hygienic packing, barcoding, and nutrition labeling (Singh *et al.*, 2012) ^[65]. Also, food safety and quality control certification, along with FSSAI compliance, Good Agricultural Practices (GAP), and organic certification, enhances marketability and consumer

confidence in value-added products (Nain, *et al.*, 2020) ^[44]. These programs increase entrepreneurship and employability among rural youth and farmers (Singh *et al.*, 2025) ^[67].

Public-Private Partnerships (PPP)

Public-private partnerships have the potential to drive large-scale scaling up of post-harvest interventions (Narrood, *et al.*, 2007) ^[46]. The private sector provides cutting-edge technology, business models, and funds, whereas public institutions provide credibility, outreach, and policy endorsement. Joint ventures could comprise setting up rural aggregation centers, solar-powered cold storage facilities, mini food processing centers, and packaging facilities. For instance, agribusiness companies can partner with self-help groups or panchayats to operate local processing centers. These partnerships guarantee sustainable operations, lower

the cost burden on farmers, and facilitate market linkages for value-added products (Patil, *et al.*, 2016) ^[54].

Farmer Producer Organizations (FPOs)

FPOs are joint ventures established by groups of small and marginal farmers to enhance their access to markets, finance, and infrastructure (Shree, *et al.*, 2022) ^[63]. In post-harvest management, FPOs are able to procure common facilities such as threshers, graders, cold storage, dryers, and packing units, largely reducing the cost liability on individual farmers (Sudheer, *et al.*, 2021) ^[69]. FPOs also enable bulk marketing of value-added products through wholesale buyers, retailers, and e-commerce. Extension agents have an important role in FPO capacity building helping with formalities, governance education, business planning, and development of linkages with financial institutions and processing industries (Prabhavathi, *et al.*, 2023) ^[55].

Table 3: Government Extension Schemes Influencing Post-Harvest Practices

S.No.	Scheme/Program	Key Influence on Post-Harvest Management
1	Mission for Integrated Development of Horticulture (MIDH)	Support for post-harvest infrastructure like cold storage, pack houses, ripening chambers Training & capacity building for farmers
2	National Horticulture Mission (NHM) (<i>now part of MIDH</i>)	Promotion of integrated post-harvest management Financial support for value addition and cold chain development
3	Rashtriya Krishi Vikas Yojana (RKVY-RAFTAAR)	Encourages agri-entrepreneurship in processing, packaging, and storage Grants for post-harvest innovations
4	Pradhan Mantri Krishi Sinchayee Yojana (PMKSY - Per Drop More Crop)	Though irrigation-focused, it indirectly supports quality produce which enhances storability and shelf life
5	Pradhan Mantri Formalisation of Micro Food Processing Enterprises (PMFME)	Financial and technical support to micro-units Capacity building for food processing, packaging, labeling
6	Operation Greens (under MoFPI)	Support for reducing post-harvest losses of Tomato, Onion, Potato (TOP) crops Subsidy on transportation and storage
7	National Agricultural Market (e-NAM)	Facilitates online marketing and better price realization Reduces distress sales and need for long-term storage
8	Agri-Clinics and Agri-Business Centres (ACABC)	Promotes agri-preneurs providing post-harvest advisory services Encourages enterprises in packaging, storage, and value addition
9	Krishi Vigyan Kendras (KVKs)	Conduct training, demonstrations, and frontline extension on scientific harvesting, handling, and storage
10	National Food Security Mission (NFSM)	Includes pulses, coarse cereals, fruits & vegetables Promotes post-harvest technology adoption through awareness and incentives
11	Small Farmers Agribusiness Consortium (SFAC)	Supports Farmer Producer Organizations (FPOs) in setting up post-harvest units Promotes aggregation and value chain development
12	Pradhan Mantri Kisan SAMPADA Yojana (MoFPI)	Focuses on mega food parks, cold chain, agro-processing clusters Aims at reducing waste and increasing processing capacity

Demonstration Units and Model Villages

Demonstration units and model villages provide real-life demonstrations of effective post-harvest interventions (Mvumi, and Stathers, 2020) ^[43]. These installations demonstrate technologies such as low-cost zero energy cool chambers, community drying yards, solar tunnel dryers, and primary processing machines in real-world field conditions. Such on-the-ground demonstrations overcome the skepticism factor and promote adoption. For example, a "model village" demonstrating integrated post-harvest solutions from field sorting to packaging and cold storage can serve as a regional knowledge centre (Abhilash *et al.*, 2021) ^[1]. Exposure tours, training camps, and contact with farmers in these regions lead to a domino effect where neighboring villages take up similar practice.

Gender-Responsive and Youth-Focused Interventions

Women are thoroughly engaged in the post-harvest operations including cleaning, grading, drying, and food

processing (Brandtzaeg, 1982) ^[12]. Yet their contribution remains informal and unpaid. Gender-specific extension strategies focus on equipping women with specific training in food preservation, packaging, hygiene standards, and small-scale value addition industries like pickle or snack making (Saikia *et al.*, 2021) ^[60]. Likewise, youth involvement is also crucial for modernization and innovation. Agri-startups, rural food processing units, farm product e-commerce, and training in packaging design, branding, and digital marketing provide promising avenues for rural youth, stemming migration and increasing income diversification (Khan 2024) ^[32].

Policy Advocacy and Institutional Support

Good extension also entails advocating for facilitating policies and institutional arrangements that favor post-harvest development (Mohammed, and Tokala, 2018) ^[41]. Extension agents can serve as bridges between farmers and policymakers by recording grassroots needs e.g., absence of

storage, restricted access to credit, or lack of training facilities and advocating for inclusion in government programs (Tomar, 2023) ^[75]. Policies in schemes such as Mission for Integrated Development of Horticulture (MIDH), PM Formalization of Micro Food Processing Enterprises (PM-FME), Agricultural Infrastructure Fund (AIF), and Atma Nirbhar Bharat offer financial and technical assistance. It is critical to ensure that these schemes are farmer-oriented, inclusive, and connected

Successful Case Studies

India: ICT-Based Tomato Value Chain Enhancement in Karnataka: Karnataka has become a leader in the use of Information and Communication Technology (ICT) in agricultural value chains, especially for perishable products such as tomatoes (Ramappa, *et al.*, 2016) ^[58]. The state government, in partnership with national research centers, private agritech companies, and local farmer groups, undertook an integrated strategy to enhance post-harvest handling and marketing efficiency in the tomato value chain (Beriya, *et al.*, 2021) ^[8]. The program aimed at digitizing access to information, minimizing post-harvest losses, and equipping farmers with real-time decision-making tools.

Project Framework and Key Interventions

The project aimed at modernizing the tomato value chain and was spearheaded by the Karnataka State Department of Horticulture in collaboration with the Indian Institute of Horticultural Research (IIHR), Bengaluru, and private agritech startups. Several key interventions were implemented to streamline operations and empower farmers: Mobile-Based Advisory Services provided real-time voice calls and messages offering guidance on optimal harvesting periods, anticipated market arrivals, price trends, and best handling practices. These advisories were tailored to specific zones and crop stages (Gajanana, 2023) ^[21].

Digital Infrastructure at Collection Points was established, including digital weighing machines, mobile-based procurement software, and barcode-based tracking systems at farm-gate procurement centers. These tools minimized pilferage, improved transparency, and expedited transactions.

Weather and Pest Forecasting Tools such as m-Kisan, Krishi Yantra, and other decision-support systems issued early warnings on rainfall, temperature shifts, pest outbreaks, and storage suggestions, enabling farmers to plan and respond proactively.

Building and Strengthening Farmer Producer Companies (FPCs) was a central intervention. FPCs like the Sri Chamundeshwari Farmer Producer Company in Kolar were equipped with upgraded infrastructure, including grading and sorting lines, solar dryers, and cost-effective storage facilities. These collectives promoted group marketing, collective bargaining, and investments in post-harvest equipment.

Integration with Digital Marketplaces allowed farmers to sell their produce on platforms such as e-NAM, e-Uparjan, and through partnerships with online retailers like BigBasket and Reliance Fresh. This shift led to better price discovery, bulk purchase arrangements, and reduced dependency on traditional intermediaries.

Impact Assessment

Reduction in Post-Harvest Losses was one of the major outcomes. Real-time advisories helped farmers align their harvest schedules with market demand, thus avoiding

oversupply and minimizing spoilage and delays in transportation. In pilot areas, post-harvest losses reduced by an estimated 20-25%.

Increased Price Realization was observed due to the adoption of transparent procurement processes and access to online price discovery platforms. On average, farmers received 15-20% higher prices compared to traditional commission-based selling in local markets.

Improved Supply Chain Efficiency resulted from mobile-based logistics planning and organized pick-up by FPCs, leading to more dependable deliveries, fresher produce, and faster market arrivals.

Enhanced Farmer Knowledge and Skills was achieved by training over 6,000 farmers, particularly in the Kolar and Chikkaballapur districts. Through Farmer Field Schools (FFS), KVK demonstrations, and exposure visits, farmers learned best post-harvest management practices such as using crates, proper grading, and hygienic packaging.

Case in Point: Kolar District Transformation

Kolar, also called the "Tomato Bowl of India," was a showpiece location for this effort. With the direct engagement of FPCs, ICT infusion, and specific government interventions, the district experienced quantifiable change in the tomato value chain (Singh, and Sagar, 2021) ^[66]. Agritech companies created digital sorting-packaging units and logistics apps that streamlined supply to large retail chains. Farmers also embraced vacuum-sealed packaging and plastic crates, which improved the quality of dispatch and minimized bruising during transport (IIHR (2020) ^[25].

Institutional and Policy Support

The success of the model was significantly backed by robust policy and institutional support. Initiatives such as the Rashtriya Krishi Vikas Yojana (RKVY) and the Mission for Integrated Development of Horticulture (MIDH) provided critical financial assistance for establishing cold storage facilities, pack houses, and enhancing market access. The Karnataka Agricultural Marketing Board (KAMB) facilitated market linkages by promoting electronic trading platforms and streamlining regulations to reduce dependency on intermediaries (Department of Horticulture, Karnataka, 2022) ^[14]. Furthermore, convergence with AgriTech startups like CropIn, Ninjacart, and FarmERP introduced technological innovations and backend infrastructure, which bolstered traceability, logistics, and farmer outreach.

Key Lessons Learned

Digital Extension Services Drive Adoption: The integration of mobile advisories, digital procurement systems, and remote weather alerts enabled timely interventions, reduced risks, and encouraged the adoption of best agricultural practices.

Collectivization Enhances Market Access: Farmer Producer Companies (FPCs) played a pivotal role in post-harvest management by aggregating produce, investing in shared infrastructure, and negotiating better deals for their members.

Institutional Convergence is important: The model's success relied heavily on the convergence of government schemes, private sector participation, and local capacity-

building programs. Such alignment is essential for replicating the model in other regions.

Empowered Farmers Make Informed Decisions: Access to transparent market data, digital transaction records, and training on post-harvest practices significantly improved farmers' bargaining power and decision-making autonomy.

Bangladesh: Farmer Field Schools (FFS) for Rice Post-Harvest Management: Bangladesh, being a predominantly rice-dependent country, has long struggled with substantial post-harvest losses, particularly among smallholder farmers who continue to use traditional methods for threshing, drying, and storage (Tandason *et al.*, 2023) ^[73]. To address this, the Department of Agricultural Extension (DAE), in partnership with international organizations such as the Food and Agriculture Organization (FAO) and several non-governmental organizations (NGOs), introduced targeted Farmer Field School (FFS) programs aimed at improving rice post-harvest management (Kamanda, 2022) ^[29].

The FFS initiative adopted a participatory approach wherein farmer groups engaged in season-long, hands-on learning cycles under the guidance of trained extension personnel. The intervention emphasized the use of plastic tarpaulins during threshing and drying to minimize grain contamination and reduce post-harvest losses caused by contact with soil and moisture. Additionally, improved hermetic storage bins and moisture meters were introduced to enhance storage safety, prevent pest infestations, and maintain grain quality. Farmers were also trained in timely harvesting, scientific drying techniques (with safe moisture content levels targeted below 14%), and post-harvest hygiene practices (Islam, and Sarker, 2020) ^[28].

The impact of these interventions was significant. Storage losses were reduced by approximately 25%, leading to increased profitability for participating households. The adoption of improved practices also enhanced grain quality, enabling better price realization in both local markets and procurement channels. Over 10,000 rice farmers benefited directly from these trainings, with noticeable spillover effects observed in surrounding communities as practices diffused (FAO, (2019) ^[16].

This case demonstrates the effectiveness of participatory learning models like FFS in translating research into on-ground adoption. Furthermore, it highlights that even low-cost, scalable interventions such as tarpaulins and improved bins can deliver substantial economic benefits when combined with practical skill-building. It also reinforces the importance of integrating gender-sensitive training modules, which further support household nutrition and income security.

Nepal: Women-Led Vegetable Processing Units

In Nepal, smallholder vegetable production forms a major component of rural livelihoods. However, seasonal surpluses and inadequate preservation facilities often lead to high levels of spoilage and food waste (Dangol, 2021) ^[13]. To overcome these challenges and enhance women's participation in agri-business, various development initiatives led by the Ministry of Agriculture and Livestock Development, in collaboration with UN agencies and NGOs have supported the formation and training of women-led Self-Help Groups (SHGs) for vegetable processing and value addition (Ghimire, and Pandey, 2021) ^[22].

These interventions trained rural women, particularly in the hill and Terai regions, in effective drying techniques using solar dryers and low-cost dehydration units, especially for vegetables like leafy greens, tomatoes, and chilies. Additionally, the groups were taught to produce hygienically prepared pickles and fermented items using traditional recipes with improved practices. Trainings also included essential business development skills such as packaging, labeling, branding, and marketing. Women entrepreneurs were encouraged to supply their processed products to local grocery outlets, weekly haats (rural markets), and school mid-day meal programs.

The outcomes were highly encouraging. Over 600 women received structured training and formed cooperatives that enabled collective investment in shared infrastructure and equipment. As a result, many households reported a 20-30% increase in income, particularly during off-season months when fresh produce was scarce. Moreover, the women involved experienced improved social recognition and decision-making power within their communities. These SHGs successfully built linkages with NGOs and public institutions, securing contracts and expanding their reach to institutional buyers.

This case underlines the potential of gender-responsive extension strategies to drive inclusive rural development. Small-scale, home-based processing units—when supported by training, collective action, and market access—can evolve into viable micro-enterprises. Furthermore, it illustrates how branding and packaging, though often underemphasized, are crucial for transitioning from subsistence to commercial levels of production.

Marketing System

The vegetable market faces numerous challenges due to the highly perishable nature, seasonal availability, and bulky characteristics of the produce. The aggregation and subsequent marketing of vegetables are often hindered by inadequate storage infrastructure and the absence of efficient transportation systems. These limitations frequently lead to seasonal gluts, compelling farmers to sell their produce at extremely low prices.

One of the major drawbacks in vegetable marketing is the excessive involvement of intermediaries. These middlemen dominate the trade and capture a significant share of the profit, leaving producers with a minimal margin from the final consumer price. To address these issues, it is crucial to implement a well-planned cooperative marketing system at both village and district levels. Such a system would help regulate the activities of intermediaries and streamline the marketing process.

Furthermore, effective coordination among the Agricultural Marketing Board, National Horticulture Board, and State Departments of Agriculture/Horticulture is essential. This collaboration can help design and execute an action plan for the smooth and systematic marketing of vegetables.

Challenges and Limitations

Limited Access to Technology and Infrastructure

In spite of advancements in post-harvest management with the aid of technology, rural and remote regions of India lack access to cold chain logistics, controlled atmosphere storage facilities, advanced packaging units, and efficient transportation networks. The high capital costs of such infrastructure make it infeasible for small and marginal

farmers to invest in these individually. Shortages of electricity and poor road connectivity further restrict the utilization of mechanized or energy-based systems.

Weak Extension-Research Linkages

There remains a large gap between research institutions and farmers. Post-harvest management innovations like bio-coatings for shelf-life extension, low-cost evaporative coolers, or better packaging materials tend to be limited to research papers or laboratories because of poor dissemination by extension agents. This leads to underutilization of scientific advances that could otherwise reach farmers at scale.

Inadequate Market Access and Price Volatility

Farmers engaged in value addition commonly experience difficulties to access credible and remunerative markets. There is no direct linkage to customers, intermediaries' domination, and weak price realization that deters them from investing in efficient post-harvest management practices. In addition, season fluctuation of prices and lack of storage compels distress sales without real-time market information or the use of forward contracts.

Uncertainty among the Stakeholders

The impact of post-harvest and value addition efforts is diluted by disjointed attempts by government departments, NGOs, private firms, and research institutions. Working in their isolated bubbles creates duplication of activities, ineffective utilization of resources, and mixed communication with farmers. What is needed is a coordinated, multi-stakeholder strategy that brings coherence and complementarity to efforts.

Gender and Socio-Economic Barriers

Women, who are the backbone of post-harvest activities such as sorting, drying, and food processing, usually encounter systemic hindrances. These are constrained access to credit, asset ownership, decision-making, and training. Likewise, vulnerable groups cannot join value-added businesses because of social stigma, illiteracy, and insufficient collateral for a loan, which creates unequal access to the fruits of post-harvest innovations.

Future Perspectives and Recommendations

Blending of Digital Tools and Artificial Intelligence (AI)

New technologies like AI, IoT, and machine learning have strong potential to change the way post-harvest management is approached. Predictive models can flag farmers and traders regarding the threats of spoilage, storage lifetimes, or pest attacks. IoT sensors could continuously monitor cold storage or transit container temperature and humidity. By integrating such interventions into extension mechanisms, efficiency may be enhanced, losses minimized, and traceability and food safety improved.

Setting up Rural Agri-Business Incubation Centers

Building agri-business incubation centers in rural or semi-urban locations can foster an ecosystem for prospective entrepreneurs, particularly in food processing. Such centers must make available small-scale processing machinery, packaging units, technical guidance, branding assistance, and credit as well as market linkages. ICAR, KVKs, and

SAUs can be instrumental in hosting or facilitating these centers, nurturing grassroots-level innovation.

Enhancing Research-Extension-Market Linkages

In order to fill the knowledge-to-action gap, innovation hubs, farmer-scientist interface workshops, and participatory research models must be institutionalized. These models can match research output with market demand and actual challenges. Closer collaboration among research institutions, extension services, and agri-marketing boards will also help to ensure that post-harvest innovations are commercially successful and farmer-friendly.

Increased Investment in Capacity Building and Infrastructure:

Long-term solutions need continuous investment in physical infrastructure and human capital. Examples include large-scale farmer training schemes, rural packhouse development, refrigeration transport, grading and branding facilities, and extension worker skill development. Community-based infrastructure like common dryers or bulk storage facilities can be encouraged through FPOs or co-operative models to bring down individual costs.

Policy Reforms to Encourage Private Sector Involvement:

Policies should be redirected to establish an enabling environment for private sector investment in post-harvest value chains. This could involve tax holidays for agro-processing start-ups, incentives to develop cold chains in underserved areas, and credit facilitation through streamlined loan procedures. Incentivizing agri-entrepreneurship through initiatives like PM-FME (Prime Minister's Formalization of Micro Food Processing Enterprises) can unlock indigenous potential and help alleviate rural unemployment.

Conclusion

Post-harvest management and value addition are not just complementary practices—they are essential pillars for achieving food security, rural development, and agricultural profitability. With India facing mounting pressure on natural resources and rising consumer expectations, it is imperative to move beyond primary production and focus on minimizing wastage, improving quality, and creating value. Successful extension approaches that combine participatory learning, ICT innovations, youth and women involvement, and institutional coordination present a sustainable way forward. A radical transformation towards inclusive, market-responsive, and digitally empowered extension services has the potential to catalyze rural agri-enterprise development, increase farmer incomes, and make Indian agriculture more competitive and resilient at the global level.

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