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Reducing Postharvest Loss in Fish, Animal-Source Foods, and Fruits and Vegetables

Evidence and Key Learnings from Ethiopia, India, Kenya, and Nigeria

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Key messages

- **Postharvest loss is real, but headline statistics are not backed by the evidence.** Loss in fish, animal-source foods (ASF), and fruits and vegetables (F&V) is often cited at 10–40 percent or more, but commonly cited statistics can rarely be traced back to field measurements. Where field data exist, they are typically two to five times lower than secondary estimates, and quality, economic, and nutrient losses, which can differ from physical loss, are rarely measured. Investments should be based on field-measured data (Sections 2–3).
- **Loss is concentrated in the informal sector, where it is measured least.** In each of the focus countries—Ethiopia, India, Kenya, and Nigeria—the review found both a small, regulated formal or export segment and a much larger informal segment (Box 2). Estimates of loss are lower for the formal segment, though some of this low loss reflects off-grade product being sold on at a discount in the informal sector. The review found no evidence that formal-sector solutions will spread to the informal sector on their own (Section 3).
- **Rigorous evidence is scarce overall and absent for fish.** Causal evidence exists for solar cold storage in horticulture markets in Nigeria and for slaughterhouse hygiene in Kenya, Vietnam, and Senegal. Dairy evidence is observational, causal and no evidence was found for fish, so fish effect sizes are indicative only. Impact evaluations on fish interventions represent the largest evidence gap (Section 4).
- **Cooling, drying, hygiene, and packaging show promise for reducing loss.** Most evidence comes from single sites or small samples, however, and uptake is often low (Section 5).
- **Technology is rarely the sole reason that scale-up stalls.** The cases reviewed suggest that the problem lies in equipment installed without a matching business model, awareness without financing or adoption support, and training where basic infrastructure, such as piped water, is missing. The literature offers varied explanations, and the lessons we present are hypotheses rather than tested findings (Sections 7–8).
- **Deliberate design is needed to include women and smallholders.** Women make up most of the postharvest workforce in fish value chains, yet gender evidence is nearly absent for ASF and limited for F&V. Cooperative and platform members benefit most from interventions, leaving nonmember smallholders in the informal sector the most exposed (Section 9).

Introduction

According to commonly cited statistics, postharvest loss (PHL) in the fish, animal-source food (ASF; meat, offal, dairy, and eggs),[1] and fruit and vegetable (F&V) subsectors represents 10–40 percent or more of production in Ethiopia, India, Kenya, and Nigeria (Sections 2–3). It leads to lost income for farmers, fishers, and processors; forgone nutrition; and a regressive burden on poor populations from the informal sector and on women, who make up most of the postharvest workforce in fish value chains, the one subsector with strong gender evidence (Section 9). This summary draws on a rapid evidence review of the three subsectors and covers the magnitude of loss, evidence of what works to reduce losses, necessary enabling conditions, and implications for investment.

This review used a two-stage literature search that began with a broad scan and then targeted searches by technology and country across academic databases, gray literature, and CGIAR repositories. The evaluation of the magnitude of loss was based on the food loss database developed by the Food and Agriculture Organization of the United Nations (FAO) (FAO, World Bank, and UNEP, 2024) and then extended to include primary field studies, a more defensible basis for determining investments than modeled or small-sample estimates. Evidence on effectiveness was grouped into three tiers: Tier A includes causal evidence that is experimental or quasi-experimental with a comparison group, Tier B includes case-study or observational evidence without a comparison group, and Tier C includes market- or system-level and feasibility evidence relevant to scaling. Details are provided in the accompanying Synthesis Report and the review protocol (IFPRI, 2026b). The findings were also discussed at a stakeholder consultation in Addis Ababa, Ethiopia, on September 24, 2026, organized by the Gender, Climate Change, and Nutrition Integration Initiative (GCAN), with about 20 experts and practitioners from the four focus countries.

Magnitude of postharvest loss

In this review, PHL includes losses that occur immediately after harvest through the retail stage. These include physical (quantity), quality, economic, nutrient, and food safety losses. The available evidence largely captures physical loss, but it rarely includes economic and quality loss, and almost never captures nutrient or food safety loss. Field data are scarce, with the most data existing for F&V and the least for fish, and estimates vary widely depending on measurement method (Table 1). Headline figures are often repeated without being backed by field data (e.g., Kruijssen et al., 2020). Secondary and modeled evidence shows that F&V has the highest average rate of loss, reflecting the perishability of these products. The ASF subsector has the lowest aggregate headline estimates of loss, but informal-segment loss is far less studied and likely higher, so low aggregate estimates may understate loss where the poorest producers and consumers conduct transactions. For fish, loss estimates fall between F&V and ASF, with the greatest formal/informal split of the three subsectors.

Working definitions. In this summary, “formal” refers to segments of a value chain that are registered, regulated, and inspected, and usually add processing, packaging, or cold storage. These segments may also be called cooperative, modern, or export segments. Informal segments, which may also be called “traditional,” operate largely outside licensing and inspection. These have little capital or cooling, and they sell mostly unprocessed products through direct sales, small traders, and wet markets. The distinction between formal and informal segments should be read as a continuum that differs by value chain (Box 2), so estimates of loss for formal and informal segments are not strictly comparable across subsectors.

[1] This category includes meat, offal, dairy, and eggs.

Table 1. Synthesis of PHL estimates

Subsector	Best-evidence central range	Where loss concentrates
Fish	Formal/export ~5% (commonly cited); informal/artisanal 30–40% (isolated cases >50%; Kruijssen et al., 2020; Abelti and Teka, 2024)	Handling stage (36% of the sub-Saharan Africa total); quality loss is 50–70%+ of total loss in several studies (Abelti and Teka, 2024)
Meat, offal, and eggs	Field-measured loss in India of 2.71% for meat and 7.19% for eggs versus modeled estimates of ~27% for meat in Kenya and Nigeria; informal-segment loss largely unmeasured (Jha et al., 2015; Aragie et al., 2023)	Pre-slaughter handling and transport, slaughter, and the retail wet market; quality loss such as carcass downgrading ("dark-cutting") is largely unmeasured (see Section 5)
Dairy	Formal/cooperative <1–3% (India <1%; Kenya ~2–3%); Ethiopia 2.1–4.3% across the main raw and pasteurized pathways but 7–41% in milk-shed surveys (see Box 2; Minten et al., 2021; Jha et al., 2015; Lore et al., 2005; Fekata et al., 2023)	Formal segment: small losses, mainly from farm to collection; traditional segment: larger losses, linked to lack of cooling and distress price discounting (Box 1)
Fruits and vegetables	Primary field measurement 10–30%; secondary/review estimates 40–75% (see Section 3)	Wholesaler-to-retail linkage is the least measured and most loss-prone stage

Loss measurements are further complicated by the difference between physical and economic loss. This applies to all the review's focus commodities and is most pronounced in dairy, where unsold fresh milk can be processed into cheese and other products. Whether this counts as a loss is debatable, and FAO does not include it in its loss estimates. Of all the data covered by this review, dairy has the strongest field evidence, and it illustrates a pattern that likely holds across subsectors: physical loss (quantity discarded) can differ widely from economic loss, which is the value lost through downgrading of quality, price discounting, and milk withheld because producers expected it could not be sold. The gap between physical and economic loss is likely largest in the traditional segment. Box 1 summarizes the price, repurposing, and loss evidence identified for milk. It is illustrative only: no study measures economic loss in this sense in the four countries.

Box 1. Milk: Price differences, repurposing of unsold milk, and indications of economic loss

Price differences between milk and byproducts. Our calculations exclude labor, fuel, and spoilage costs and mixing years and segments. In Ethiopia, butter alone sells for about 12–25 percent less than the equivalent amount of milk per liter, but butter plus *ayib* cheese sells for about 14–22 percent more; fasting reduces milk, butter, and cheese prices by 3–5 percent, 7–8 percent, and 18 percent, respectively (D'Haene et al., 2021; Debele, 2012). In India, surplus skimmed milk powder is about 27–30 percent below milk (Menon, 2018; Dairy Dimension, n.d.). In Kenya, farmgate prices fell 45 percent during a glut (Business Daily, 2020). No comparison was found in Nigeria.

Repurposing of unsold milk. Findings from Kenya (Nakuru) indicate that of rejected milk, about 60 percent of farmers make fermented milk, 15 percent dispose of it, and 25 percent feed animals or neighbors (Ndungi et al., 2021); forced on-farm consumption is valued at 30 percent of the farmgate price (Lore et al., 2005). In Ethiopia, fasting raises the processed share by about 20 percentage points (D'Haene et al., 2021). Nigeria includes *nono* and *wara* (Iyiola-Tunji et al., 2019), while India includes powder, butter, ghee, and paneer (Menon, 2018).

Indications of economic loss and the data gap. These are illustrative only. Physical loss is lower in formal segments (<1 percent in India, about 2–3 percent in Kenya) and higher in traditional ones (3–5 percent in Kenya, 1–2 percent in India; Lore et al., 2005; Jha et al., 2015). Economic loss can differ from physical loss in gluts, fasting seasons, and when milk is rejected. Unverified stakeholder estimates (formal/traditional) are 15–25 percent/35–50 percent in Ethiopia, 2–5 percent/5–10 percent in India, 5–8 percent/20–30 percent in Kenya, and 20–35 percent/40–60 percent in Nigeria. No study in the four countries measures milk (1) intended for sale but not sold, (2) reprocessed rather than fully lost, or (3) not offered for sale because producers expect it cannot be sold.

Box 2. Working definitions of formal and informal, by value chain

Formal segments are registered, regulated, and inspected; informal segments are not. This distinction differs by value chain, though most studies do not distinguish between formal and informal. India's national averages (Jha et al., 2015) are not differentiated by segment.

Dairy. Formal segments include pasteurized, packaged milk from licensed processors, or milk bulked and chilled through cooperatives. Informal segments include raw milk sold directly or through unlicensed traders and vendors. Pasteurization is only a proxy, because licensing also matters. Estimates of milk loss in Ethiopia (2.1–4.3 percent) cover the most prevalent raw and pasteurized pathways (Minten et al., 2021), so these are not formal-only figures.

Fish. Formal includes plants and exporters approved and inspected for export markets (for example, MPEDA-regulated exports in India). Informal includes artisanal landing, smoking, drying, and local trade.

Meat. Formal includes export and licensed abattoirs with meat inspection. Informal includes slaughter slabs and wet markets with little inspection. This review uses this distinction, though the sources rarely define it.

Eggs and fruits and vegetables. Formal includes export and organized retail such as supermarkets. Informal includes wet markets and smallholder-to-trader sales. This review uses this distinction.

Differences in estimates of postharvest loss

Field-measured evidence on PHL is limited across the three subsectors, especially fish and meat. Where field data are available, they indicate that actual loss is typically two to five times lower than commonly cited secondary or FAO-modeled estimates of the same commodity in the same country. This gap is partly due to differences in definitions: FAO's Food Loss Index counts only physical loss that is discarded, excludes distress-sale discounting and quality downgrading, and relies on sparse government questionnaires supplemented by model-based estimates.

- **India's national ICAR-CIPHET surveys** (two rounds) find losses of 0.92 percent for milk, 2.71 percent for meat, and around 10 percent for F&V (Jha et al., 2015), all of which are far below commonly cited modeled statistics (Aragie et al., 2023). The surveys do not cover long-haul transport to terminal markets or market excess, so they may understate later-stage losses.
- **Ethiopia's dairy survey**, a large representative survey tracking milk from farms to Addis Ababa (Minten et al., 2021), finds loss of just 2.1–4.3 percent along the most prevalent raw and pasteurized pathways. Across products, modern retail loses about half as much as traditional retail. Smaller milk-shed surveys in other regions, which do not distinguish formal from informal segments, find loss ranges of 7–41 percent (Fekata et al., 2023, 2025; averages of 40.5 percent, 17.3 percent, and 7.2 percent in the three milk sheds surveyed).
- **Primary field surveys of tomato in Kenya and Nigeria** show losses of 28 percent and 10–22 percent, respectively, and controlled storage experiments on mango show 13–18 percent weight loss (Gatere et al., 2022; Takeshima et al., 2023; Amwoka et al., 2021). These are well below secondary or modeled estimates of 40–75 percent for the same crops (Ridolfi et al., 2018).
- **Headline figures on fish**, which commonly estimate losses of "up to 40 percent," are similar to estimates from primary studies that range from 7.6 percent in Kainji Lake, Nigeria, to 53 percent in Tagwai Lake, Niger State (as reviewed in Abelti and Teka, 2024), showing how sensitive the headline number is to the study cited.

The practical implication of this evidence is that investment sizing and economic modeling (Aragie et al., 2023) should prioritize field-measured studies over modeled or small-sample estimates, and should treat any headline PHL statistic with caution, unless its source and method are stated.

Two patterns help explain the variation in PHL estimates and affect decision-making on investment: the formal/informal divide and seasonality, especially in the F&V subsector.

The formal/informal divide: The most consistent finding

All three subsector reviews found that each focus country has both a small, regulated formal or export segment and a much larger informal segment (Box 2) that handles most domestic volume. Loss appears to be concentrated in the informal segment, where it is also measured far less reliably.

- **Fish**: Loss is commonly cited to be around 5 percent in the formal/export segment and 30–40 percent in the small-scale, informal segment (Table 1). The split is starkest in Kenya, where EU-driven export standards on Nile perch date from the 1997–2000 period (Odoli et al., 2019), and in India, where the Marine Products Export Development Authority (MPEDA) sets export standards and inspects processing plants. Studies describe India's domestic system as being "highly unorganized" (Hatte et al., 2022). In Kenya, the informal segment consists of small-scale fish landing, smoking, drying, and local trade, often at landing sites where, in a 2016 survey, only 16 percent of installed cold rooms were operational (Odoli et al., 2019).
- **Dairy**: The Ethiopian gap above (up to tenfold) is between studies that differ in design and do not distinguish formal and informal segments. In Kenya and India, dairy cooperative members show better food safety compliance and cold-chain access than nonmembers, who are the majority of smallholders in most studies reviewed (Nyokabi et al., 2026; Katoch et al., 2024).
- **Meat, offal, and eggs**: Export-oriented abattoirs are a small formal segment; most volume passes through informal slaughter slabs and wet markets that are measured least well. Quality losses such as dark-cutting are not captured by physical loss metrics.
- **Fruits and vegetables**: Formal and informal segments differ not only in the extent of loss but also the reasons for it. Strict standards for product appearance in formal markets can lead to edible produce being discarded, whereas informal retailers often sort produce into grades and discount lower-quality items (Boiteau and Pingali, 2026). The wholesale-to-retail stages, where trade is largely informal, are the least measured parts of the chain.

A related caveat: some of the formal sector's apparent efficiency reflects how loss is measured, but it does not necessarily represent efficiency gains. For fish, products that are off-grade or rejected by export-standard processing may be offered at a discount in the informal sector (Abelti and Teka, 2024). Low measured loss in the formal sector can therefore partly reflect a shift of value loss downstream: the product is sold rather than discarded, but it is offered at a discount and may deteriorate further.

The evidence reviewed does not support the assumption that formal-sector solutions will spread to the informal sector, which handles most volume and supports most people's nutrition and income. Doing so will require strategies designed for the conditions of the informal sector: limited access to capital, inputs, information, and markets; misaligned incentives; and weak institutional trust.

Seasonality in fruits and vegetables: A distinct driver of loss

Many F&V commodities, especially tree crops, are harvested in highly concentrated time periods (seasonality is generally weaker for vegetables). Combined with weak market information, this leads to excess supply that exceeds what local markets can absorb, forcing distress sales and on-farm dumping, even where produce has been handled well. Indian tomato value chains provide the clearest evidence of this loss (Boiteau and Pingali, 2022): quality losses are lower during peak supply periods, when trading and transport are pre-

pared for volume, but the return to investing in PHL-reduction technology is also lower, because high supply depresses prices regardless of quality; the reverse situation occurs during off-peak periods. A single figure on yearly average losses or a cost-effectiveness estimate can therefore mislead in either direction. Evidence on seasonal patterns is largely absent for Ethiopia, Kenya, and Nigeria, but the same dynamics are likely, and market information systems may help allocate supply.

A similar mismatch between concentrated demand or supply and fixed capacity occurs in Ethiopia's fish subsector, where consumption is higher during Orthodox fasting seasons, and in dairy, where fasting reduces annual milk consumption by an estimated 12 percent and pushes producers toward storable products (D'Haene et al., 2020). India's flush-season milk surpluses follow the same pattern. Holiday peaks in meat demand show up in prices, but their link to loss has not been measured. Three implications follow: assess and finance processing and storage capacity for peak-season absorption, not average throughput; invest in market-information and demand-forecasting systems, since matching supply with demand can be a loss-reduction intervention; and time evaluations and adoption support to coincide with the crop's seasonal calendar, since the same technology can pay off in one part of the season but not another.

Impact and effectiveness of interventions and innovations to reduce postharvest loss

Analysis using the three-tier evidence framework identifies an uneven evidence base across the three subsectors. Table 2a presents the evidence for Tier A, and Table 2b provides evidence for Tiers B and C. For dairy, Tier B and C evidence adds milk-cooling pilots in Kenya and Uganda and the Anand Milk Union Limited (AMUL) and Kenyan cooperative models, which are institutional templates, not evidence of effect size. Tier B and C evidence is limited for fish and meat and largest for F&V, but it mostly comes from station-scale trials.

Causal evidence is available for meat, offal, and egg hygiene and for F&V, though the meat evidence concerns hygiene practice and sales rather than PHL magnitude, and the F&V evidence is geographically narrow. Evidence for dairy is observational or institutional. There is no causal evidence for fish across the four countries. As a result, every claim on fish effect size should be considered indicative until impact evaluations are completed; these claims include the approximately 20 percent increase in income from ice-box access in India (Wu et al., 2026) and the loss-reduction estimates for solar drying and smoking kilns. The lack of impact evaluations for fish is the highest-priority evidence need.

Table 2a. Tier A (causal) evidence on intervention impacts and effectiveness

Subsector	Does Tier A (causal) evidence exist in the four countries?	What does the evidence evaluate?
Fish	None identified in Ethiopia, Kenya, Nigeria, or India	Closest approximations only: India (Esser et al., 2007; controlled but not randomized)
Meat, offal, and eggs	Yes: the largest randomized controlled trial (RCT) cluster of the three subsectors	Hygiene and food safety RCTs in Kenya, Vietnam, and Senegal (Cook et al., 2025; Dang-Xuan et al., 2025; Ambler et al., 2024; Orou Seko et al., 2022); these measure hygiene practice, sales, and prices, not physical loss, and effects on microbial contamination are inconsistent
Dairy	None identified on PHL outcomes; two quasi-experimental studies in Kenya measure income and welfare rather than loss (Ngeno, 2018; Smale et al., 2012)	India's Food Safety Index study (Katoch et al., 2024; n=341): higher food-safety compliance is associated with higher milk procurement prices, but the design is observational; the cooling pilots and cooperative models in Table 2b are not causal evaluations

Subsector	Does Tier A (causal) evidence exist in the four countries?	What does the evidence evaluate?
Fruits and vegetables	Yes: narrower but more directly relevant to PHL	Nigeria's ColdHubs cluster (RCT/quasi-experimental): a 4.7-percentage-point reduction in loss overall and 11 points for produce held in cold stores, from a baseline of about 13 percent, plus revenue and sales-volume gains (Takeshima et al., 2021, 2023)

Table 2b. Tier B (observational) and Tier C (market- and system-level) evidence on interventions

Subsector	Tier B: Observational and case-study evidence	Tier C: Market- and system-level evidence
Fish (14 observational; 8 laboratory, model, or review studies)	14 observational studies (Nigeria = 6, Kenya = 4, Ethiopia = 2, India = 2), mostly on drying, smoking, and ice. Examples: a solar dryer in India cut batch drying time from 38 hours to under 24 hours, raised dried-fish revenue by about 50%, and paid back in 1.2 years (Andharia et al., 2022). Single-site designs without comparison groups; loss itself is rarely measured.	Modeling suggests net fish utilization could rise from 54% to 66–74% at 50–80% adoption of loss-reducing technology, which the authors call an upper limit (Wu et al., 2026). Laboratory trials of natural preservatives and company-reported platform results say little about PHL. Kenya's Nile perch case shows export infrastructure can cut loss yet cause overfishing and conflict (Kruijssen et al., 2020).
Meat, offal, and eggs (1 observational; 4 laboratory, model, or review studies)	One study in the focus countries: group-based hygiene training in Bodija Market, Nigeria, improved the microbial quality of meat (Grace et al., 2012). Outside the focus countries, evidence includes a Senegal quasi-experimental study (Traoré et al., 2021) and qualitative user experiences with a household meat safe in Bangladesh (Rahman et al., 2026). The evidence concerns hygiene, not physical loss.	Pay-per-use cooling of the ColdHubs type (58+ Nigerian markets, mostly horticulture) is flagged as transferable to meat but is untested there (Stathers et al., 2024). Egg evidence includes only one laboratory coating trial in India. Ethiopia's hypochlorous-acid work for meat is unpublished: an earlier sensory trial and a carcass field experiment are planned for 2026 (IFPRI, 2026a).
Dairy (9 observational; 3 laboratory or model studies)	About nine observational studies, mostly in Kenya. Solar and evaporative milk-cooling pilots report earnings gains of US$23–650 per household per month and 1–3-year paybacks from self-reported data (Foster et al., 2015); quality and food-safety surveys (Nyokabi et al., 2026); and India's Food Safety Index study linking compliance to milk price (Katoch et al., 2024).	India's AMUL cooperatives pair village-level collection and chilling with quality-based payment and have operated at a national scale for decades (NDDB, n.d.-a, n.d.-b), although about a quarter of village societies were weak or dysfunctional in one World Bank evaluation (Candler and Kumar, 1998, as cited in Rajagopalan, 1999). Kenya's cooperative creamery network nearly collapsed after market liberalization in 1992 (Atieno and Kanyinga, 2008), and about 80% of milk is still marketed informally (Blackmore et al., 2022). Both are institutional templates, not evidence of effect size.
Fruits and vegetables (122 observational; 33 laboratory, model, or review studies)	The largest body: 122 studies (India = 59, Nigeria = 30, Kenya = 24, Ethiopia = 16), mostly storage and shelf-life trials of evaporative cooling, packaging, and coatings. For example, in Kenya, a charcoal cooler held tomato weight loss to 6.2% versus 16.2% in ambient storage over 48 hours (Ronoh et al., 2020). Most studies are graded only "indicative."	Platform results (Twiga Foods in Kenya, PricePally in Nigeria) are company-reported and unevaluated, and Twiga entered administration in 2026 (Section 5). ColdHubs reports scaling to 58+ markets (Stathers et al., 2024), a company-reported figure that has not been independently audited.

Note: The number of studies reported in the table represents unique studies in the four focus countries from the project evidence databases. Those databases label tiers differently than this review does: database Tier C = causal, which is Tier A in this report; database Tier A = laboratory, model, review, and expert-opinion studies, which only partly corresponds to Tier C here. Tier C evidence in this report also draws on program and company reports that are not in the databases and cannot be counted.

What consistently works across two or more subsectors?

- **Sustained cold-chain access delivered as a service, not asset ownership.** The evidence on pay-per-use cooling models illustrates similar patterns across fish, dairy, and F&V: for fish, fish sellers in India reported an income gain of about 20 percent, though this reverted when access lapsed (Wu et al., 2026); for dairy, households reported US$23–650 per month and 1–3-year paybacks from solar and evaporative cooling in Kenya and Uganda (Foster et al., 2015); and for F&V, overall loss declined by 4.7 percentage points, and it declined by 11 points for produce held in cold stores in Nigeria's ColdHubs (Takeshima et al., 2021, 2023). However, the strength of the evidence differs between these subsectors: for F&V, evidence is quasi-experimental, and for fish and dairy, it is case-study or self-reported. Overall, the transferable lesson is that the pay-per-use "cooling-as-a-service" model (ColdHubs, in more than 58 Nigerian markets; Stathers et al., 2024) fits users' daily cash flow and avoids upfront capital, though subsidized fuel may weaken scalability. In Kenya, solar freezers are offered on rent-to-own terms at about US$2 per day over 15 months (Royal Academy of Engineering, 2024) or about US$35 per month over about three years (WorldFish, 2025). These provider-reported prices appear affordable to many small traders and processors of relatively profitable commodities (Takeshima et al., 2023).

- **Low-cost drying and processing technologies.** Low-cost solar drying shows consistent but indicative benefits for fish: in Ethiopia, reductions in loss of up to 24.9 percent were reported for solar tent dryers and 14.9 percent for raised racks, though the baseline was unspecified (Abelti and Teka, 2024); in Cambodia, solar-dryer users produced about five times more and earned higher prices and incomes than processors using traditional drying (Hin et al., 2024); and in India, using a walk-in solar dryer repaid initial costs within 1.2 years (Andharia et al., 2022; single site). A global modeling study cites low-cost dryers as costing about US$24 in India, with 2–3-month paybacks, and US$55–170 in Malawi (Wu et al., 2026). However, none of these is a causal design. For F&V, solar drying shows proof of concept, but adoption is limited and uneven.

- **Handling, hygiene, and grading practice bundles.** Evidence on the fish subsector in Kenya showed the strongest quantitative association: in a survey of 94 cultured-tilapia actors in one county, a nine-variable model explained 87 percent of variation in loss, with sanitary conditions, training, water quality, and cooling among the significant predictors (Obar et al., 2025). Hygiene bundles are plausibly among the cheapest levers to pilot, although costs were not compared across interventions. Pairing basic carcass grading with pre-slaughter handling and transport-stress reduction may help address "dark-cutting" meat, a carcass downgrade caused by pre-slaughter stress. Two small Ethiopian studies found dark, firm, dry meat in roughly 8–30 percent of beef samples (Bekuma and Tadesse, 2024; Gibore et al., 2023); stakeholder estimates are 25–40 percent in Ethiopia, 15–28 percent in Nigeria, and 8–15 percent in Kenya (stakeholder consultation, 2026), but we found no published prevalence for Nigeria or Kenya. Grading allows sellers to assign a higher price for quality improvements, which hygiene training alone does not.

- **Improved reusable packaging.** In Nigeria, reusable plastic crates were associated with reductions in tomato loss of roughly 10–15 percentage points among Lagos traders (Aghadi et al., 2020); a larger reduction, from roughly 40 percent to 10 percent, was cited at the stakeholder consultation but could not be traced to a published source. Evidence from Ethiopia is more mixed. GAIN's E-PLAN project distributed about 19,000 plastic crates on the Meki–Addis Ababa tomato route; implementer and wholesaler estimates put loss at about 5–7 percent in plastic crates versus 15–20 percent in wooden crates, with no sampling protocol described (GAIN, 2022). A separate nine-trial comparison over about 600 km from the Central Rift Valley to Harar found that plastic crates led to more intact fruit and less microbial contamination, but lower profitability than wooden crates for most of the year (Gemeda et al., 2026). The use of plastic crates in the informal sector was estimated at under 1 percent, against a 10–20 percent critical

mass, and rental and subsidy models were judged unsustainable without outside support (GAIN, n.d.). We found no independent adoption data beyond the pilot.

- **Demand-aggregation and price-transmission platforms**, where they have been evaluated. Labels showing origin and cool transport on tomato crates raised sale prices by roughly 10–20 percent in randomized field experiments in Nigeria (Yamauchi et al., 2024, 2026). Similar evidence is lacking for fish or ASF digital platforms, however, despite comparable or greater investment. Kenya's Twiga Foods reported that loss in the informal segment fell from roughly 30 percent to less than 5 percent while the company was operational (cited in Ambuko and Owino, 2023), and Nigeria's PricePally reports comparable loss reduction (GSMA, n.d.); neither claim has been independently evaluated, and Twiga entered financial administration in 2026 (Tech Trends Kenya, 2026). A platform's loss reduction results and its financial durability are separate questions, and both need independent verification before any company is treated as an investment template.

- **Non-punitive, low-stakes inspector monitoring.** In Kenya's RCT of abattoir hygiene, a bundle of training, equipment, and low-stakes meat-inspector monitoring improved worker practices by about 0.8 standard deviations while it ran, with smaller gains noted four weeks after monitoring ended. The authors suggest that monitoring can be an effective regulatory tool, although the trial could not separate its effects from those of training and equipment (Cook et al., 2025). This is suggestive evidence that non-punitive approaches can work in low-capacity settings, where punitive enforcement risks pushing production into the informal sector.

- **Low-adoption technologies.** These have demonstrated effectiveness, though this does not guarantee uptake**.** Several interventions with demonstrated benefits show stalled or low adoption, including the Nigerian Stored Products Research Institute (NSPRI) smoking kiln and the Ice-Fish Box (Section 7 and Table 3), and reusable plastic crates, which were adopted by only 17 percent at harvest and 12.6 percent at marketing (Yami et al., 2025). Even in the evaluated ColdHubs markets, cold stores were used well below capacity two years later (Takeshima et al., 2026). Awareness and a favorable cost-benefit case may not be enough; adoption may depend on frictions that differ by technology, such as unit cost relative to daily cash flow, fit with trading practice, and trust (Section 8).

What holds promise but needs more evaluation?

- **Digital business-to-business and market-coordination platforms in fish and ASF.** These platforms represent the largest mismatch between investment activity and evidence identified in the review. Platforms such as Captain Fresh, Aquaconnect, and Agrovesto are proliferating across all four countries (Captain Fresh reported tenfold revenue growth in 2021), but no rigorous evaluation of PHL reduction was found; figures are self-reported by the companies and not independently verified.

- **Natural preservatives, biocontrol agents, and chemical decontamination.** Laboratory results across all three subsectors are promising: for example, garlic-ginger extract extended the shelf life of vacuum-packed herring from 3–4 to 8 weeks (Ahmed et al., 2019), and plant-extract antifungal dips have been tested for F&V. IFPRI planned a hypochlorous-acid field experiment to decontaminate carcasses in Addis Ababa for 2026 (unpublished; IFPRI, 2026a), but unpublished project findings from Kenya suggest limited consumer acceptance of such treatments. Field validation is almost nonexistent in low- and middle-income countries, so the next step should be a small field pilot in each subsector rather than direct scale-up.

- **Landing-site, harbor, and market infrastructure investment.** These investments can plausibly reduce PHL in all three subsectors, but more evidence is required: infrastructure has often been built without a governance or business plan (Section 7), so demonstrated impact at scale is lacking.

What does not work or works only under specific conditions?

- **Infrastructure investment without governance, business-model, or utilization design.** This is a cautionary finding across subsectors, though it is based on a few heterogeneous cases. At the 557 Kenyan landing sites reviewed, only 16 percent of installed cold rooms, 15 percent of drying racks and solar dryers, and 39 percent of smoking kilns were operational (Odoli et al., 2019). A government-funded 2-tonne cold-storage unit at a farmers' market in Madurai, Tamil Nadu, stored 0.5–1.0 percent of the market's arrivals (Lavanya et al., 2020). These cases suggest—but do not prove—that technologies do not deliver benefits by themselves, and business-model and governance design should precede technological investment.

- **Awareness-building without adoption support.** In Nigeria, about 87 percent of surveyed Ice-Fish Box recipients were aware of the box and willing to use it, but the study measured stated willingness only, not adoption, loss, or income (Ajayi et al., 2022). For the NSPRI smoking kiln, only about 23 percent of surveyed processors were willing to pay the expected price, which the authors link to limited awareness and high initial cost (Omotesho et al., 2019). Awareness is not the same as adoption, nor is adoption the same as impact, so dissemination should be paired with financing and followed by measurement of adoption and outcomes.

- **Training and behavior change interventions where an infrastructure, resource, or belief constraint is left unaddressed.** Kenya's slaughterhouse RCT shows that training, equipment, and monitoring shifted practices and raised throughput (an exploratory outcome) while the program ran, but the interventions did not reliably reduce carcass contamination. Pointing to the narrow scope of the intervention bundle (training, equipment, and monitoring) and the lack of piped water, the authors suggest that higher throughput and crowding may have offset hygiene gains (Cook et al., 2025). A Bangladesh trial on household meat storage reportedly found the storage device was used correctly (87–99 percent), but there was no measurable health benefit (Rahman et al., 2026; trial results not verified). For fish, Fiji's sea-cucumber study (Purcell et al., 2024) shows training improved individual effort and prices but not household income where the fishery stock was declining. This suggests that postharvest interventions cannot substitute for resource management when a decline in stock, not handling, is the binding constraint.

- **Market-linkage investment without resource or equity safeguards.** Kenya's Nile perch case shows that export-driven infrastructure reduced fish PHL but also drove overfishing and local conflict (Kruijssen et al., 2020), a trade-off rather than a costless win.

Enabling environment: Where do promising investments fell short and why?

Governments, donors, and programs have invested in technically sound technologies and reforms and, in some cases, even formally adopted them as policy, yet these investments delivered only partial results. In certain cases, this shortcoming appears to be explained by implementation and institutional factors, not the technology itself (Table 3). This distinction matters: technologies that do not work require different solutions than those that were not implemented under enabling conditions that facilitate their success. The cases in

Table 3 are illustrative and context-specific: they come from studies designed for other purposes, differ in quality and scale, and do not evaluate the merit of the programs involved.

Table 3. Lessons on barriers to scaling and enabling conditions for promising innovations

Where/when?	What happened?	Underlying cause and remedy
Kenya, small-scale fisheries: government- and donor-funded landing site infrastructure surveyed in 2016 (Odoli et al., 2019)	Of 557 landing sites reviewed, ice, jetties, potable water, and roads were almost all operational, but only 16% of installed cold rooms, 15% of drying racks and solar dryers, and 39% of smoking kilns were operational; export processors used less than 150 of 429 tonnes of daily installed capacity. Training in drying was reported to have good results.	The authors attribute underuse to weak regulation, no system to monitor use, limited credit and business orientation among users, and unreliable water and electricity, and they recommend feasibility studies, beneficiary co-contribution, and monitoring before further investment. A plausible implication is the need to test siting, operating, and maintenance arrangements before building; the review cannot show which factor mattered most.
Madurai, Tamil Nadu, India: one 2-tonne cold storage unit at a government farmers' market, 2012/13–2016/17 (Lavanya et al., 2020)	The unit stored 0.5–1.0% of the market's annual arrivals; 13–16% of participating farmers used it, and the average quantity stored per user rose over the period.	The authors do not explain why most farmers did not use the unit, and they call for a primary study of farmers' perceptions. A plausible implication is that user needs and fit should be studied before replicating small market-level units; a single-market case cannot show whether this holds elsewhere.
Western Kenya: randomized trial of slaughterhouse hygiene training, equipment, and inspector monitoring in 140 rural facilities (Cook et al., 2025; not yet peer reviewed)	Worker hygiene practices improved by about 0.8 standard deviations during monitoring, water and knife contamination fell, and throughput rose (about 8–12% at midline, an exploratory outcome). Carcass contamination did not decline: it was higher at midline in one arm and not significantly different at endline. Practice gains were smaller four weeks after monitoring ended.	The authors attribute the limited carcass effect to the narrow scope of the intervention bundle (for example, visibly dirty animals arriving, and no pre-slaughter cleaning because only about 20% of facilities had piped water) and tentatively suggest that higher volume and crowding may have offset practice gains. They conclude that the bundle was insufficient for the public health objective. A plausible implication is the need to assess water access before designing hygiene programs and to track throughput alongside contamination.
Nigeria: NSPRI smoking kiln (Kwara State) and Ice-Fish Box (Lagos State) promotion (Omotesho et al., 2019; Ajayi et al., 2022)	In a Kwara State survey, catfish smoked in the kiln was most preferred and the kiln was profitable, yet only about 23% of processors were willing to pay the expected price. In Lagos, about 87% of surveyed Ice-Fish Box recipients were aware of it (81.8% in the paper's abstract) and willing to use it for preservation and transport, but not for processing or curing. Neither study measured adoption, losses, or income.	The kiln authors suggest limited awareness and high upfront cost, and recommend extension plus grants, loans, or lower prices. The Ice-Fish Box evidence only concerns stated willingness. A plausible implication is that promotion should be paired with financing options and adoption and outcomes should be measured alongside awareness; these small studies cannot show why adoption is low or how it would change with support.
Ethiopia (2024) and Kenya (2024–2028): national postharvest management strategies (MoA, 2024; MoALD, 2024)	Ethiopia's strategy covers grains, horticulture, and animal-source foods and requires more than ETB 14.3 billion (MoA, 2024); Kenya's covers crops, livestock, and fisheries and is estimated to cost about KSh 3.29 billion over five years (MoALD, 2024). The strategies and an independent review of Ethiopia's policy framework acknowledge weak coordination, limited trained personnel or budget allocation, and limited enforcement (Gosa, 2026).	It is too early to assess implementation. Participants in the stakeholder consultation perceived that attention and funding still favor grains and horticulture (stakeholder consultation, 2026), which we could not verify because the budgets we reviewed do not show a commodity split. A plausible implication is the need to track whether commodity-specific budget lines and implementing capacity for fish, meat, and dairy follow the stated scope.

Note: Unless stated otherwise, explanations are those of the cited authors. NSPRI = Nigerian Stored Products Research Institute.

Programs that worked through existing institutions show more encouraging results, but these are still nascent. In Kenya, county veterinary directors said they were willing to integrate hygiene training and inspector monitoring into routine operations if resources allowed, noting needs for funding, staff, water, and consumables (Otoigo et al., 2024). In Ethiopia, a stakeholder consultation reported that the Addis Ababa City Food and Drug Administration was a partner in an ongoing meat-decontamination trial, though we could not verify this claim. In Nigeria, ColdHubs reduced market-level losses, although units were used well below capacity (Takeshima et al., 2023, 2026). Taken together, the cases suggest that (1) technologies benefit from prior siting, ownership, and business-model design, (2) infrastructure such as water should be assessed before the start of behavior change programs, and (3) financing and adoption support should be planned alongside dissemination or policy expansion. However, these are hypotheses from a few heterogeneous cases, not tested findings.

Distributional findings: Gender and smallholders

Gender evidence is highly uneven across subsectors, which is a finding in itself.

- **Of the three subsectors, fish has the richest gender evidence.** Women represent most of the postharvest workforce in the fish value chains studied, with 56–99 percent of processing workers, including 99 percent of catfish processors in Lagos State, Nigeria, and 88 percent of farmed-fish traders surveyed in Zambia, although their share of trading is almost nonexistent in some settings (0–1 percent in Bangladesh). The evidence largely comes from aquaculture chains, and sex-disaggregated data remain scarce (Kruijssen et al., 2018). In a small survey of capture-fishery camps in Zambia, female processors lost about three times as much of their fish consignments as male processors (16.5 percent vs. 5.4 percent; Kaminski et al., 2020). Gender-transformative training (Fiji; Purcell et al., 2024) and gender-responsive behavior-change design (Zambia; Cole et al., 2020) produced larger equity and income gains than generic approaches.
- **F&V has limited gender evidence.** An evaluation of Ethiopia's Smallholder Horticulture Empowerment and Promotion (SHEP) program (Fikadu et al., 2025) finds that household decision-making moderates income gains, though the bundled design prevents isolating the postharvest component.
- **ASF has essentially no gender evidence, representing the weakest base of the three subsectors and a low-cost gap to close.** Of the studies on meat, offal, dairy, or egg found for the four countries, none reports sex- or age-disaggregated PHL, income, or time-use outcomes. The only gender-relevant finding is a qualitative observation that women are underrepresented in postharvest service roles such as cold-chain service operations. Future ASF studies and programs should collect sex-disaggregated data from the outset.

For smallholders, cooperative or platform membership is consistently associated with better technology access and prices, as seen in Kenyan and Indian dairy cooperatives, Ethiopian and Kenyan fishery cooperatives, and F&V farmer organizations. Nonmember smallholders in the informal segment are most exposed to loss and least likely to benefit from current investment, without deliberate inclusion through mobile collection or aggregator financing.

Concluding remarks

The evidence does not point to a single missing technology. For the core technologies considered—cold chain, drying, packaging, and hygiene practices—benefits are achieved and may be inexpensive, but the quality of the evidence varies. Robust quantification of reductions in loss and evaluation of the barriers to adoption are missing across the fish, ASF, and F&V subsectors. Needs include sustained access through

viable business models, governance arrangements that accompany technologies, and rigorous evaluation of platforms that attract much of the current investment. The design of interventions should account for the informal sector and for gender gaps: women make up most of the postharvest workforce in fish value chains and, in one Zambian study, they lost more product than men, but their role in ASF chains is largely unstudied.

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