CHAPTER 21

Insects and Food Security in Developing Economies: Threat, Opportunity, and the Institutions That Decide Which Prevails

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Abstract

Insects occupy a paradoxical position in food security science. They are simultaneously among the most destructive forces acting against food systems and among the most underexploited resources for strengthening them. Pre-harvest pest damage and postharvest storage losses attributable to insects remove a substantial share of the food that developing economies produce before it ever reaches a plate. While, at the same time, insects themselves represent a nutrient-dense, resource-efficient food and feed source that remains largely outside formal food systems and regulatory frameworks. This chapter argues that which of these two faces predominates in any given country is not primarily a biological or technical matter but an institutional one. Drawing on the desert locust upsurge of 2019–2021, the spread of fall armyworm across Asia and Africa, and the slow institutionalization of insect farming and entomophagy in countries such as Thailand, the chapter develops the Insect-Mediated Food Security Framework (IMFSF), which models net food security impact as the difference between institutionally mediated losses avoided and institutionally mediated value captured. The framework is applied in depth to Pakistan, where weak extension delivery, pesticide subsidy distortions, fragmented quarantine authority, and an absent regulatory pathway for insect-based food and feed products together constrain both sides of the ledger. The chapter closes with a sequenced set of governance recommendations addressing surveillance and early warning, integrated pest management institutionalization, and the regulatory foundations needed to convert insects from food security liability into a food security asset.

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1. Introduction

Organizing Question: How do insects simultaneously undermine and offer pathways to strengthen food security in developing economies, and what institutional conditions determine which effect dominates in each country's context?

Food security scholarship has generally treated insects as a peripheral concern, addressed, if at all, under the heading of crop protection, and rarely brought into contact with the central debates over governance, institutions, and political economy that animate the rest of this volume. This treatment understates the scale of the issue. Insects intersect with food security through at least two distinct and largely separate channels. The first is destructive: insect pests reduce the quantity and quality of food available for human consumption at every stage from the field to the storage bin, and a small number of migratory and invasive species can inflict continental-scale damage in a single season. The second is productive: a subset of insect species are edible, nutritionally dense, and can be reared with a fraction of the land, water, and feed inputs required by conventional livestock, offering a potential food and feed resource that most developing economies have neither regulated nor integrated into agricultural or nutrition policy.

This chapter treats these two channels not as separate topics but as two pathways of a single phenomenon, governed by overlapping but distinct sets of institutions. Consistent with the volume's central argument, that food insecurity in developing economies is fundamentally a governance problem rather than a production problem, this chapter shows that the same institutional weaknesses that limit the effectiveness of subsidy programs, decentralization, and price stabilization elsewhere in the book also determine whether insects function as a net drain on or a net contribution to national food security. Where extension systems, quarantine authority, and regulatory capacity are strong, pest losses can be substantially contained and emerging opportunities in insect-based food and feed can be captured. Where these institutions are weak, fragmented, or politically compromised, both the loss pathway and the gain pathway underperform simultaneously.

Pakistan is used as the chapter's primary case study, both because it is the volume's dominant geographic focus and because it illustrates the dual failure mode with particular clarity: a country that has experienced significant, institutionally amplified pest losses in the recent past, including the 2019–2020 desert locust upsurge, while simultaneously possessing almost no regulatory or policy architecture for insect-based food or feed, despite favorable agroecological and economic conditions for their development. Comparative evidence from Thailand's cricket farming sector, sub-Saharan Africa's fall armyworm response, and the regulatory approaches of the European Union and the Food and Agriculture Organization (FAO) is used to illustrate what functional institutions look like on both sides of the ledger.

2. The Scale of the Problem: Insect-Mediated Losses in Developing Food Systems

Global estimates place insect-attributable losses among the largest single biotic constraints on realized crop production, alongside pathogens and weeds, with the burden falling disproportionately on the tropical and subtropical regions where most developing economies are located, both because pest pressure is generally higher under warm, humid conditions and because the surveillance, extension, and control infrastructure needed to contain that pressure is generally weaker (Oerke, 2006; Savary *et al*., 2019). This asymmetry means that the same insect species can impose a materially different food security cost depending on where it occurs, a point developed further in Sections 3 and 5.

2.1. Pre-Harvest Losses

Insects are estimated to destroy a substantial proportion of global crop production every year, with losses concentrated disproportionately in developing economies where pest surveillance, extension coverage, and access to timely control measures are weakest (Oerke, 2006; Savary *et al*., 2019). Unlike losses from abiotic stress, insect-driven losses are frequently preventable with timely, well-targeted intervention, which is precisely what makes the scale of realized loss in developing economies an institutional signal rather than a purely biological one. Three pest complexes illustrate the point with force in the South Asian and Pakistani context.

Cotton, historically Pakistan's most important cash crop and export earner, has for decades absorbed a disproportionate share of national pesticide use in response to the cotton bollworm complex and, since the mid-2000s, the cotton mealybug and whitefly-transmitted cotton leaf curl virus complex. Yield losses in poorly managed fields have periodically exceeded a third of potential production, with associated foreign exchange and rural income consequences that extend well beyond the farm gate (Hameed *et al*., 1993; Nawaz *et al*., 2019; Brar & Bhullar, 2022).

Stored-grain pests, chiefly Sitophilus species, Tribolium species, and the khapra beetle, impose losses that are less visible than field-level pest outbreaks but are frequently larger in aggregate, because they act continuously across the storage period rather than in a single seasonal event, and because storage infrastructure in developing economies is frequently informal, poorly ventilated, and lacking basic pest exclusion.

The most dramatic recent illustration of pre-harvest insect risk in the region, however, is the desert locust (Schistocerca gregaria) upsurge of 2019–2021, discussed in detail in Section 2.3, which affected Pakistan alongside East Africa, the Horn of Africa, and parts of the Arabian Peninsula and South Asia simultaneously, and which functioned as a stress test of national and regional pest governance capacity under conditions of genuine transboundary emergency.

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2.2. Postharvest Losses

Post-harvest losses are attributable to insects compound pre-harvest losses and are frequently underestimated in national food balance accounting, because they occur diffusely across millions of individual storage decisions made by smallholder farmers, traders, and processors rather than at a small number of observable points in the supply chain. Estimates for cereal postharvest losses in developing regions, encompassing insect damage alongside fungal spoilage and mechanical loss, commonly range from a fifth to a third of harvested grain under poor storage conditions (Affognon *et al*., 2015; APHLIS, 2021), a magnitude that, if halved, would represent a larger addition to effective food availability than most feasible increases in planted area or yield. Because postharvest loss reduction does not require new land, water, or seed, and because it acts directly on food that has already been produced at real resource cost, it constitutes one of the more institutionally tractable levers available to food security policy, provided storage infrastructure, extension advice on hermetic storage technologies, and market incentives for quality-based pricing are in place.

2.3. Case Study: The 2019–2021 Desert Locust Upsurge as a Governance Stress Test

The desert locust upsurge that began in the Horn of Africa in 2018 and spread across East Africa, the Arabian Peninsula, Iran, and into Pakistan and northwestern India by 2019–2020 was, by most assessments, the most serious locust event in a quarter century (FAO, 2021). Pakistan declared a national emergency in early 2020 after swarms affected Balochistan, Sindh, and southern Punjab, with early estimates suggesting billions of dollars in potential crop and economic losses if the upsurge had not been contained (Government of Pakistan, 2020).

The episode is instructive less for its biology, desert locust population dynamics are comparatively well understood, than for what it revealed about institutional capacity. Locust control depends on continuous field surveillance in remote breeding areas, rapid reporting into regional early warning systems, cross-border data sharing, and the capacity to mobilize aerial and ground control assets before hopper bands fledge into highly mobile swarms. Pakistan's response drew on FAO coordination and international support, and ultimately avoided the catastrophic scenario, but exposed long-standing weaknesses in provincial-federal coordination on plant protection, in the staffing and equipment of the Department of Plant Protection, and in the country's capacity to sustain surveillance during non-emergency periods, when funding and attention for locust monitoring characteristically lapse. This pattern, underinvestment during quiescent periods followed by crisis-driven emergency response, is a recognizable institutional signature that recurs across pest management systems in developing economies and is addressed directly in Section 3.

2.4. Climate Change as a Loss Multiplier

The loss burden documented above is not static. Rising temperatures are projected to expand the geographic range and shorten the generation time of many economically important insect pests, while also altering the synchrony between pest life cycles and crop phenology in ways that existing pest management calendars, built around historical climate patterns, do not anticipate (Deutsch *et al*., 2018). This dynamic connects the present chapter directly to the climate-vulnerability analysis developed in Chapter 11 and the adaptive-governance argument developed in Chapter 12: static pest management institutions, calibrated to a pest complex and geographic distribution that climate change is actively reshaping, will underperform even where they historically performed adequately, unless surveillance and extension systems are redesigned with the scenario-planning and trigger-based logic that Chapter 12 recommends for food security governance more broadly. Fall armyworm's rapid establishment across Asia after its 2016 African detection, aided by the pest's strong flight capacity and broad host range, is itself illustrative of the kind of range expansion that a warming climate is expected to make more common across a wider set of species, reinforcing rather than replacing the institutional argument developed in Section 3.

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3. The Loss Pathway: Why Pest Management Institutions Underperform

3.1. Extension and Surveillance Gaps

Integrated pest management (IPM) has been promoted internationally as the technical standard for pest control since at least the 1970s, combining biological control, resistant varieties, cultural practices, and judicious, targeted pesticide use in place of calendar-based spraying. Its adoption in developing economies, however, has consistently lagged its technical promotion, for reasons that are substantially institutional rather than technical (Parsa *et al*., 2014). Extension services in most developing economies, including Pakistan, are underfunded relative to the geographic and farmer populations they are meant to serve, meaning that farmer-level pest identification and threshold-based decision-making, the foundation of IPM, is frequently replaced by default reliance on prophylactic pesticide application, reinforced by input dealers who have a direct financial incentive to recommend more spraying rather than less.

3.2. Pesticide Subsidy and Market Distortions

Where fertilizer subsidies distort input markets elsewhere in this volume's analysis (Chapter 6), pesticide markets in many developing economies exhibit a related but distinct distortion: weak regulation of the retail pesticide trade allows the proliferation of counterfeit and substandard products, inconsistent enforcement of pre-harvest intervals and restricted-use classifications, and a commission-based sales structure that rewards volume over efficacy. The consequence is a pest management system in which farmers frequently overspend on pesticide inputs while simultaneously achieving suboptimal pest control, a combination that is only fully explained by reference to the incentive structure of the retail input market rather than to farmer knowledge deficits alone.

3.3. Fragmented Quarantine and Regulatory Authority

Plant quarantine and pest surveillance functions in many developing economies, Pakistan included, are split across federal and provincial authorities with overlapping but incompletely coordinated mandates, a pattern that parallels the decentralization risks identified elsewhere in this volume (Chapter 5): unfunded mandates, fragmentation, and exclusion of the technical capacity needed to act on surveillance data even where it exists. Transboundary pests such as fall armyworm (Spodoptera frugiperda), first confirmed in Africa in 2016 and detected across South and Southeast Asia by 2018–2019 (Goergen *et al*., 2016; FAO, 2019), spread in significant part because no developing region possessed the coordinated, real-time surveillance and rapid-response architecture that a genuinely invasive, highly mobile pest requires. Fall armyworm is now established across most of Pakistan's maize-growing areas and functions as a recurring, rather than emergency, drain on maize yields, illustrating how an initial governance failure to prevent or slow an invasion becomes a permanent addition to the baseline loss burden.

3.4. What Functional Institutions Look Like

Not all developing-economy pest governance is weak, and the contrast is informative. National surveillance and early-warning systems that maintain year-round field networks rather than crisis-triggered mobilization, that integrate remote sensing and mobile-based farmer reporting (a theme explored further in Chapter 17's treatment of digital tools), and that combine biological control research capacity with rapid regulatory approval for new biocontrol agents, have demonstrated materially better outcomes against comparable pest pressure. Kenya's post-2016 fall armyworm response, which built on existing plant health surveillance infrastructure developed for earlier pest threats, is frequently cited as a comparatively effective regional model (Day *et al*., 2017), underscoring that the binding constraint is institutional continuity and coordination capacity rather than the availability of the underlying control technologies.

3.5. The Political Economy of Pest Management Reform

The persistence of calendar-based, high-input pesticide reliance despite decades of IPM promotion is best understood, in terms consistent with the political economy framework Chapter 6 applies to subsidy and price-control persistence, as the product of a distributional coalition with a direct stake in the status quo.

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Agrochemical companies and the retail dealer networks through which pesticides reach farmers constitute a well-organized, geographically dispersed interest group with clear incentives to resist reforms that would reduce input volumes, while the diffuse beneficiaries of reduced pesticide overuse, farmers who would save on input costs, downstream consumers exposed to lower pesticide residues, and the environment more broadly, face the classic collective action problem of a benefit too widely dispersed to generate organized political pressure (Olson, 1965, as applied in Chapter 6's framework). This asymmetry helps explain why IPM adoption in developing economies has typically advanced fastest not through broad regulatory reform of the pesticide market, which requires confronting the organized coalition directly, but through donor-funded farmer field school programs that build farmer-level demand for reduced-input approaches without directly challenging the retail input market structure, a second-best but politically more feasible reform pathway that nonetheless leaves the underlying market distortion in place once donor funding ends. A durable solution, consistent with the sequencing logic developed in Section 8, likely requires pairing farmer-facing IPM promotion with parallel, incremental strengthening of pesticide retail regulation and enforcement, so that gains in farmer demand for reduced-input approaches are not undermined by a retail market still structurally biased toward overselling.

4. The Gain Pathway: Insects as an Underexploited Food and Feed Resource

4.1. The Nutritional and Resource-Efficiency Case

A substantial body of research, consolidated most influentially in FAO's 2013 report *Edible Insects: Future Prospects for Food and Feed Security* (van Huis *et al*., 2013), documents that many edible insect species are comparable to or exceed conventional meat sources in protein content and quality, and are frequently rich in essential fatty acids, iron, zinc, and other micronutrients in which diets in food-insecure populations are commonly deficient. The resource-efficiency case is at least as significant for food security purposes as the nutritional case: farmed insects such as crickets and black soldier fly larvae generally require substantially less land, water, and feed per unit of protein produced than cattle, and in some analyses than poultry, while producing a fraction of the greenhouse gas emissions (Oonincx & de Boer, 2012; van Huis, 2013). For land- and water-constrained developing economies facing simultaneous pressure to raise protein availability and manage climate commitments, an efficient protein source that can be produced on marginal land, fed partly on agricultural and food waste streams, and cycled in weeks rather than months represents a genuinely underused asset.

4.2. Entomophagy: Existing Practice and the Acceptance Barrier

Entomophagy, the human consumption of insects, is already practiced by an estimated two billion people worldwide, concentrated in parts of Southeast Asia, sub-Saharan Africa, and Latin America, where insects such as crickets, grasshoppers, termites, and various beetle larvae form a traditional part of local diets (van Huis *et al*., 2013). South Asia, including Pakistan, has comparatively limited traditional entomophagy practice and correspondingly strong cultural resistance to insect consumption as food, a pattern that has meaningfully slowed policy and market development relative to Southeast Asia even where the underlying agroecological potential is comparable. This acceptance barrier is real and should not be minimized, but international experience suggests it is more tractable when insects are introduced as processed ingredients, insect flour incorporated into familiar products such as bread or snack foods, rather than as whole, visually recognizable insects, and when introduction is paired with credible food-safety certification that addresses the (generally low but non-zero) allergenicity and contamination risks associated with insect products (Sogari *et al*., 2019).

4.3. Insect Farming for Animal Feed: A Lower-Barrier Entry Point

Where entomophagy faces a direct consumer acceptance barrier, insect-based animal feed faces a substantially lower one, since the insects are consumed by livestock, poultry, or farmed fish rather than by people directly, while still displacing conventional feed ingredients, chiefly fishmeal and soymeal, whose production carries its own food security and environmental costs. Black soldier fly (Hermetia illucens) larvae have emerged as the leading candidate species for feed applications because they can be reared on organic

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waste streams, including agricultural byproducts and food waste, converting a disposal cost into a protein input (Nyakeri *et al*., 2017). Given this volume's separate treatment of aquaculture as an underrepresented pillar of food security (Chapter 7), the connection is direct: insect-based feed represents one of the more promising pathways for reducing the fishmeal dependence that currently constrains the environmental and economic sustainability of aquaculture expansion in exactly the coastal developing economies that Chapter 7 examines.

4.4. The Regulatory Vacuum

The single largest constraint on the gain pathway in most developing economies, and in Pakistan specifically, is not biological, technical, or even primarily cultural, but regulatory. Novel food and feed regulatory frameworks capable of classifying insect species for human consumption or animal feed use, setting food-safety and contamination standards, and providing a licensing pathway for insect-farming enterprises are largely absent. The European Union's novel food regulation, which since 2021 has authorized several insect species for human consumption subject to specified safety assessments (EFSA, 2021), and Thailand's decades-long, informally regulated but increasingly formalized cricket-farming sector, now estimated to comprise tens of thousands of small-scale farms supplying both domestic and export markets (Hanboonsong *et al*., 2013), illustrate two different institutional pathways, formal ex ante regulation and gradual formalization of organic market development, by which the regulatory vacuum can be closed. Pakistan currently has neither.

4.5. Nutritional Comparison and the Scale-Up Question

The nutritional argument for insects as food and feed is strongest in comparative terms. On a dry-weight basis, many farmed edible insect species provide protein content comparable to beef and poultry, with crickets and mealworms typically falling in a range of roughly 45 to 65 grams of protein per 100 grams of dry matter, alongside favorable ratios of unsaturated to saturated fat and meaningful concentrations of iron, zinc, and vitamin B12, nutrients for which deficiency remains widespread among food-insecure populations in developing economies (van Huis *et al*., 2013). The resource case scales in the same direction: because insects are poikilothermic and exhibit high feed-conversion efficiency, farmed crickets have been estimated to require roughly twelve times less feed than cattle and roughly half the feed of poultry to produce an equivalent quantity of protein, with correspondingly lower land and water requirements (van Huis, 2013; Oonincx & de Boer, 2012). These figures should not be read as implying that insect farming can or should substitute wholesale for existing livestock systems, on which rural livelihoods and cultural practice depend; the more realistic and policy-relevant claim is narrower, that insect-based feed can displace a meaningful share of the fishmeal and soymeal currently imported or diverted from human-edible grain stocks, and that insect-based food ingredients can supplement, rather than replace, existing protein sources in nutritionally vulnerable populations, particularly where introduced as processed ingredients rather than whole insects, as noted above.

5. The Insect-Mediated Food Security Framework (IMFSF)

5.1. Framework Logic

This chapter proposes the Insect-Mediated Food Security Framework as an integrated model for assessing and governing the dual role of insects in national food security. The framework's central proposition is that the net food security contribution of insects in each country (NFSC) can be represented as:

NFSC = (Losses Avoided through the Loss Pathway) + (Value Captured through the Gain Pathway)

where both terms are functions of institutional quality rather than of insect biology or agroecological potential alone, which are comparatively fixed. The Loss Pathway is mediated by four institutional variables: surveillance and early-warning capacity, extension delivery, quarantine and cross-jurisdictional coordination, and input-market regulation. The Gain Pathway is mediated by four parallel institutional variables: novel food/feed regulatory capacity, research and development investment in rearing and processing technology, market and value-chain development, and public communication and acceptance-building capacity. A country with strong institutions on both sets of variables realizes low pest losses and high captured value from insect-based food and feed; a country weak on both, the Pakistani pattern documented in this chapter, realizes high losses and negligible captured value, representing the worst available combination on the underlying biological endowment. Critically, the framework predicts, and the Pakistani case illustrates, that the two pathways are not independent: the technical, surveillance, and extension capacity built for the Loss Pathway, entomological expertise, laboratory and diagnostic infrastructure, field networks, is substantially transferable to the Gain Pathway, meaning that investment in one need not compete with investment in the other and may in fact create shared institutional foundations.

5.2. Positioning within the Volume

The IMFSF is intended to occupy a position in this volume analogous to the Global Marine Food Security Index proposed in Chapter 7: both frameworks respond to a domain, marine food systems and insect-mediated food security respectively, that has been treated in the wider literature as a specialist subsector rather than integrated into mainstream food security assessment, and both argue that the domain's proper treatment requires an institutional rather than a purely technical or production-focused lens. Where GMFSI is constructed as a scored, multidimensional index suited to cross-country benchmarking, the IMFSF is deliberately framed as a diagnostic and planning framework rather than a numerical index, reflecting the earlier stage of data availability and institutional development in the insect-food-security domain; a natural extension of this chapter's contribution would be the future construction of a scored index once national-level data on pest losses, extension coverage, and insect-farming activity become more systematically available.

5.3. A Diagnostic Summary Table

Table 21.1 summarizes the eight institutional variables of the IMFSF and provides a qualitative rating of Pakistan's current status on each, drawn from the diagnosis developed in Section 6. The table is intended as a diagnostic and planning tool rather than a scored index; assigning numerical weights to these variables in a way that supports cross-country comparison is identified in Section 5.2 as a priority for future research.

Table 21.1: IMFSF Institutional Variables: Qualitative Diagnosis for Pakistan

Pathway	Institutional Variable	Current Status in Pakistan
Loss	Surveillance and early-warning capacity	Weak; event-driven rather than continuous
Loss	Extension delivery	Weak; low IPM-trained extension worker-to-farmer ratio
Loss	Quarantine and cross-jurisdictional coordination	Fragmented; federal-provincial mandate overlap
Loss	Input-market regulation	Weak; counterfeit and substandard pesticide circulation
Gain	Novel food/feed regulatory capacity	Absent; no regulatory category exists
Gain	R&D investment in rearing/processing	Minimal; negligible relative to livestock research
Gain	Market and value-chain development	Absent; no organized insect-feed supply chain
Gain	Public communication and acceptance-building	Absent from extension and nutrition programming

6. Case Study: Pakistan through the IMFSF Lens

6.1. Loss Pathway Diagnosis

Applying the framework's four Loss Pathway variables to Pakistan yields a consistent diagnosis. Surveillance and early-warning capacity is event-driven rather than continuous, as the 2019–2020 locust emergency

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illustrated, with staffing and funding for the Department of Plant Protection contracting during non-crisis periods. Extension delivery is thin relative to farmer population, with agricultural extension worker-to-farmer ratios well below recommended levels in most provinces, and IPM-specific training reaching a small minority of smallholders. Quarantine and cross-jurisdictional coordination is complicated by the division of agricultural authority between federal and provincial governments following the Eighteenth Constitutional Amendment, a devolution dynamic examined in general terms in Chapter 5, which in the plant protection domain has produced exactly the risk pattern that chapter identifies: unfunded provincial mandates, fragmented reporting, and uneven capacity across provinces without the matched finance and national minimum standards needed for devolution to function well. Input-market regulation of the pesticide retail trade remains weak, with counterfeit and substandard product circulation documented by industry and government sources alike, reinforcing farmer overreliance on calendar-based spraying (Figure 21.1).

6.2. Gain Pathway Diagnosis

The Gain Pathway diagnosis is, if anything, starker. Pakistan has no novel food or feed regulatory category for insect products, meaning that any prospective insect-farming enterprise faces not a burdensome approval process but an absent one, a governance gap rather than a governance obstacle. Public and private research and development investment in insect rearing and processing technology is minimal relative to the scale of agricultural research investment directed at conventional livestock and crop breeding. Market and value-chain infrastructure for insect-based feed ingredients, which would allow black soldier fly or similar operations to sell into Pakistan's substantial poultry and aquaculture feed markets, does not exist in organized form. Public communication and acceptance-building efforts around entomophagy or insect-based feed are essentially absent from agricultural extension and nutrition programming (Figure 1).

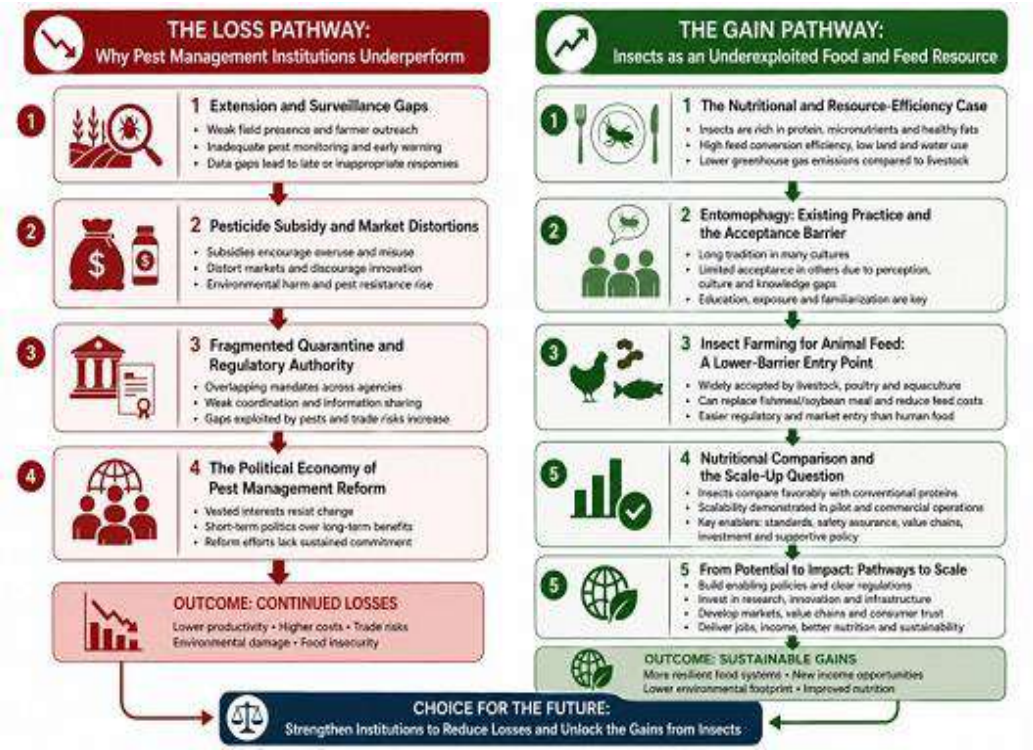

Figure 21.1: Depiction of Gain and Loss Pathways

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6.3. Institutional Failure Typology

Read against the four-type institutional failure typology developed in Chapter 4 for Pakistani food security governance more broadly, design failure, coordination failure, accountability failure, and adaptive failure, the insect-mediated food security case exhibits all four in recognizable form. Design failure is visible in the absence of any regulatory category for insect food and feed products, a gap that cannot be closed by better implementation because there is no policy design to implement. Coordination failure is visible in the federal-provincial fragmentation of plant protection authority documented above. Accountability failure is visible in the recurring pattern of crisis-driven emergency response followed by disinvestment once the immediate threat recedes, with no institutional mechanism holding surveillance capacity to a consistent standard between crises. Adaptive failure is visible in the persistence of calendar-based pesticide application and the absence of any systematic effort to evaluate or scale successful pilot IPM or insect-farming interventions into national policy, mirroring the broader adaptive-policymaking deficit that Chapter 16 identifies as a cross-cutting weakness in the region's food security governance.

6.4. Illustrative Economic Magnitudes

While a comprehensive national accounting of insect-mediated gains and losses for Pakistan does not currently exist, precisely because the surveillance and market-data systems that would generate such an accounting are among the institutional gaps this chapter identifies, illustrative magnitudes from adjacent, better-documented cases suggest the scale of what is at stake. The 2019–2020 locust emergency alone prompted government and donor estimates of potential agricultural and economic losses running into billions of dollars had the upsurge not been contained (Government of Pakistan, 2020), a single-event cost of the same order of magnitude as several years of Pakistan's total public agricultural research spending. On the Gain Pathway side, Thailand's cricket-farming sector, developed from a negligible base over roughly three decades, now generates estimated annual farm-gate revenue in the tens of millions of dollars and supports tens of thousands of largely rural, smallholder-operated farms (Hanboonsong *et al*., 2013), a scale that, while modest relative to Thailand's overall agricultural economy, represents exactly the kind of diversified, land-light rural income source that food security and rural livelihoods policy in Pakistan's own resource-constrained provinces could plausibly target. The asymmetry between a well-documented, single-event loss on one side of the ledger and an essentially undocumented, foregone opportunity on the other is itself a symptom of the institutional gap this chapter describes: what is measured tends to be managed, and Pakistan currently measures its insect-mediated losses, imperfectly, while not measuring its insect-mediated opportunities at all.

7. Comparative Evidence: What Functional Institutions Achieve

Three comparative cases illustrate that the institutional weaknesses documented in Pakistan are not inevitable features of developing-economy governance. Thailand's cricket-farming sector developed over several decades from informal household-level practice into a semi-formalized industry, now estimated at tens of thousands of farms, through a combination of extension support from Thai universities and the Department of Agriculture, gradual market formalization, and eventual engagement with export-oriented food-safety standards, illustrating a Gain Pathway development trajectory that required sustained institutional attention but not, initially, comprehensive ex ante regulation (Hanboonsong *et al*., 2013). Kenya's fall armyworm response, discussed in Section 3.4, illustrates a comparatively effective Loss Pathway response built on pre-existing plant health surveillance infrastructure rather than infrastructure created de novo during the emergency itself, underscoring the value of continuous rather than crisis-triggered institutional capacity. The European Union's novel food regulatory pathway for insect products, while developed under very different administrative and resource conditions than apply in most developing economies, nonetheless demonstrates the essential design elements, species-specific safety assessment, defined licensing procedures, and labeling requirements, that a developing-economy regulatory framework would need to adapt rather than replicate wholesale (EFSA, 2021).

Beyond these three primary cases, several smaller scale but instructive examples reinforce the pattern. Rwanda's post-genocide reconstruction of agricultural extension services, credited elsewhere in the

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comparative food security literature with above-average policy coherence and institutional capacity (Chapter 15), has also supported comparatively rapid farmer uptake of biological control and reduced-pesticide approaches for banana and cassava pests, suggesting that the general extension-system strength documented for Rwanda in other domains carries over into pest management specifically. Uganda and Kenya's parallel, university-linked pilot programs on black soldier fly rearing for poultry and aquaculture feed, though still small in absolute scale, have benefited from a comparatively receptive regulatory environment for novel feed ingredients relative to Pakistan's regulatory vacuum, allowing pilot-stage enterprises to progress toward commercial operation rather than remaining permanently confined to research settings. None of these cases represents a fully solved system; each retains its own institutional weaknesses. But taken together they demonstrate that the specific combination of continuous surveillance funding, extension systems capable of carrying new practices to farmer level, and a minimally functional regulatory pathway for novel food and feed products, is an achievable institutional configuration under developing-economy resource constraints, not a standard that only high-income countries can meet.

8. Policy and Governance Recommendations

Consistent with this volume's emphasis on politically feasible, sequenced reform rather than comprehensive but unrealistic policy prescriptions, five recommendations are proposed, ordered from lower to higher institutional and fiscal demand.

First, convert locust and fall armyworm surveillance from an emergency-triggered to a continuously funded function, with a protected budget line insulated from the funding volatility that has historically characterized Pakistan's plant protection spending. This is the lowest-cost, highest-return recommendation given the demonstrated cost of the alternative during the 2019–2021 upsurge.

Second, establish a functioning novel food and feed regulatory pathway for insect products, drawing on the European Union's framework for its technical design elements while calibrating approval requirements to Pakistan's institutional capacity, an initial focus on feed-grade applications, which carry lower food-safety stakes than direct human consumption, would allow the regulatory system to develop experience and credibility before extending to human food products.

Third, integrate IPM training into mainstream agricultural extension delivery, rather than treating it as a supplementary program dependent on donor project funding, and pair this with stronger enforcement of pesticide retail standards to reduce the counterfeit and substandard product circulation that currently undermines farmer trust in reduced-spray approaches.

Fourth, resolve federal-provincial coordination gaps in plant quarantine and pest surveillance authority through the kind of matched-finance, minimum-standards approach to decentralization recommended in Chapter 5, rather than through further ad hoc reassignment of responsibility without corresponding resources.

Fifth, direct a modest, ring-fenced allocation of agricultural research funding toward insect rearing, processing, and feed-substitution research, recognizing that the entomological and diagnostic capacity this requires substantially overlaps with the capacity needed to strengthen the Loss Pathway, meaning the marginal institutional cost of this investment is lower than a green-field research program would suggest.

These five recommendations are deliberately sequenced rather than presented as a simultaneous reform package, consistent with the political-economy realism this volume applies elsewhere to subsidy and price-control reform (Chapter 6): the first and third recommendations require reallocation of existing budgets and administrative attention rather than new legislation, and could plausibly be implemented within a single budget cycle; the second and fourth require legislative or intergovernmental coordination and should be treated as medium-term objectives; the fifth is contingent on demonstrated success in the earlier steps and on the availability of fiscal space within the broader agricultural research budget. A useful institutional entry point for several of these recommendations already exists in Pakistan's provincial agricultural universities and the Pakistan Agricultural Research Council, whose entomology departments possess much of the diagnostic and rearing expertise the Gain Pathway requires, but whose research agendas remain

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overwhelmingly oriented toward conventional crop protection rather than insect-based food and feed applications, a reorientation that would not require new institutions so much as a redirected mandate and a small, dedicated funding stream.

8.1. Implications for Future Research

Three research priorities follow directly from the diagnostic and framework contributions of this chapter. The first is the systematic collection of national-level data on insect-mediated pre-harvest and postharvest losses disaggregated by crop, region, and pest species, without which the Loss Pathway component of the IMFSF cannot be quantified with confidence and against which the return on surveillance and extension investment cannot be evaluated. The second is applied research on the technical and economic feasibility of insect-based feed substitution specifically calibrated to Pakistan's poultry and aquaculture sectors, given that the resource-efficiency case reviewed in Section 4 is drawn substantially from research conducted in other agroecological and market contexts. The third, and most directly aligned with this volume's broader methodological orientation, is the extension of the IMFSF from a qualitative diagnostic tool into a scored, cross-country index, following the analytical path Chapter 7 has already charted for marine food systems, once sufficient countries have developed the underlying loss and value-capture data this chapter finds largely absent even in Pakistan's case.

9. Conclusion

Insects will remain a permanent feature of developing-economy food systems; the open question this chapter has addressed is not whether they matter for food security, but which of their two faces, destructive or productive, a given country's institutions allow to predominate. The evidence assembled here, from the 2019–2021 desert locust upsurge to the continuing absence of any regulatory pathway for insect-based food and feed in Pakistan, indicates that the country currently captures the worst of both possibilities: substantial, recurring, and only partially institutionally contained losses on one side, and a wholly uncaptured resource opportunity on the other. Consistent with the volume's central argument, closing this gap does not primarily require new entomological science, the relevant pest management and insect-rearing technologies are, for the most part, already established internationally, but new institutional capacity: continuous rather than crisis-driven surveillance, coordinated rather than fragmented quarantine authority, and a regulatory foundation for insect-based food and feed that currently does not exist. The Insect-Mediated Food Security Framework developed in this chapter is offered as a starting point for that institutional agenda, and as an invitation to future research to extend it into a scored, cross-country index as the underlying data infrastructure matures.

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