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# Towards Sustainable Management of Insect Pests: Protecting Food Security through Ecological Intensification

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**Abstract**

Insect pests are a major constraint to food security, destroying up to 40% of global crop production annually. Pest outbreaks threaten smallholder incomes and disrupt supply, increasing market prices and reducing food accessibility for vulnerable populations. This review synthesizes evidence on strategies to minimize the negative economic impacts of insect pests and enhance the resilience of food systems. Recommended approaches include: adopting integrated pest management practices that balance multiple controls; transitioning to agroecological farming systems that boost biodiversity and ecological pest suppression; improving monitoring and rapid response to migratory pests; developing and disseminating resistant crop varieties; supporting farmer organizations and knowledge exchange networks; providing financial safety nets via insurance, credit and savings; investing in post-harvest storage and handling infrastructure; promoting livelihood diversification beyond crops; developing value-added processing for damaged crops; and raising consumer awareness to reduce waste and overconsumption. A mix of technological, organizational, and policy measures at multiple food system levels is required to reduce producer and consumer vulnerability to pest-induced supply and price shocks. Investment in ecologically based, socially-just approaches will strengthen food and economic security for those most at risk from the impacts of pest damage.

**Keywords:** Insect pests, Food security, Integrated pest management, Agroecological farming systems, Climate change.

**Full-length article**

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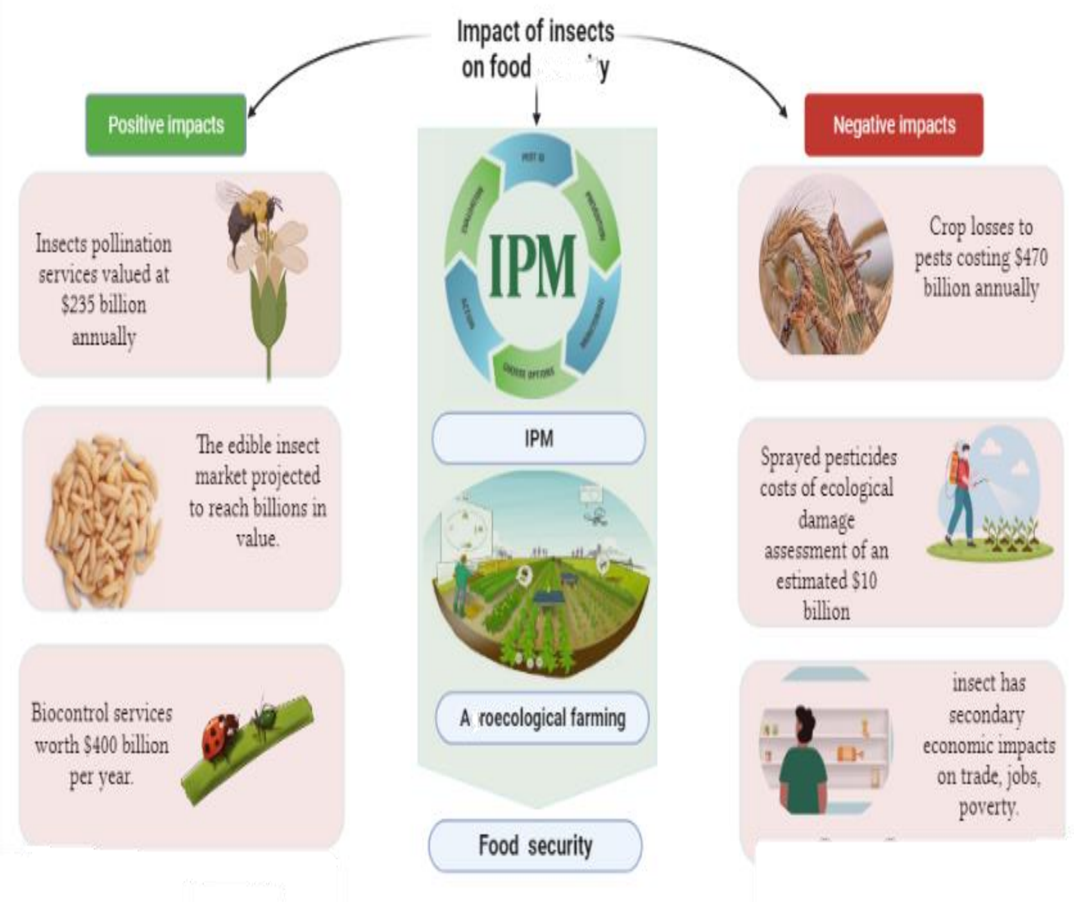
## 1. Introduction

Diabetes Insect pests are a major impediment to global food security, destroying up to 40% of food crops worldwide and posing an escalating threat as climate changes [1]. With the global population estimated to reach 9.8 billion by 2050, rising crop losses from insect pests will greatly impact food availability and access, especially in vulnerable communities [2]. This review provides an in-depth examination of the negative and positive impacts of insect pests on global food security .First, the scope and severity of global food security challenge merits discussion. According to the UN Food and Agriculture Organization (FAO), food security exists when all people have physical, social, and economic access to sufficient, safe, and nutritious food that meets dietary needs [2]. However, over 820 million people today remain chronically undernourished, concentrated primarily in low-income regions like sub-Saharan Africa and South Asia [3]. Food security is also threatened by additional stressors like climate change, land degradation, and rapidly rising global food demand [4]. In this context, insect pests are a crucial factor undermining food security and nutrition for millions worldwide. Economically, insect pests cause staggering crop losses – an estimated $470 billion USD per year as of 2001 [5]. These farm-level losses reverberate through trade networks and labor markets, impacting incomes, livelihoods, and access to food [1]. Environmentally, repeated insecticide is used to control pests, degrades ecosystems and loses natural biocontrol services from predatory insects and bats [6]. Replacing these ecosystem services would cost an estimated $4.5 trillion per year [7]. Socially, poor rural households may fall into debt traps trying to replace crop losses from pests, entrenching poverty, and food insecurity [8]. Even localized pest outbreaks can destabilize regional food supplies and prices, as exemplified by the 2004 locust plague in West Africa [2]. In a world where over two billion people lack year-round access to adequate food, the crop losses and systemic impacts wrought by insect pests cannot be overlooked [3]. There are also concerns that pest impacts will intensify under climate change, necessitating a deeper understanding of risks as well as pest ecology and management [9]. To that end, this review synthesizes current knowledge on major insect pests, their negative and positive impacts, and the outlook for balancing productivity, sustainability, and food security.




**Graphical abstract showing the impact of insects on food security**

## 2. The global economic impact value of insects in 2022 and beyond

Insects play a tremendously key role in ecosystems and human economies worldwide. Recent studies have aimed to quantify the overall economic impact and value of insects in global agriculture and food systems. van Lenteren *et al*. [10] estimated the total value of four key ecosystem services provided by insects to be over $250 billion annually as of 2022. These services included pollination, natural pest control, dung burial/decomposition, and wildlife nutrition. Insect pollination alone was valued at $235 billion based on its essential contribution to 75% of globally important crops [10]. Meanwhile, Losey and Vaughan [11] calculated the economic value of four vital insect predator groups providing natural biological pest control globally at approximately $400 billion per year. Predatory insects like ladybugs, lacewings, syrphid flies, and spiders constrain pest populations and damage diverse cropping systems [11]. This represents a massive economic contribution considering global crop losses to insect pests are estimated at $470 billion annually [12].

In terms of direct use as food and feed, the global edible insect sector was worth over $260 million in 2022 and is projected to exceed $4.6 billion by 2027 [13]. While small currently, continued efforts to mainstream entomophagy and integrate insect ingredients into foods and feeds could enable large expansion [14]. Insects require far less feed, water, and land than traditional livestock production, offering sustainability benefits [15]. Overall, these studies reveal that insects provide between $250 billion to over $1 trillion in estimated annual economic value through ecosystem services and direct provisioning. As climate change and other stressors threaten insect populations globally, quantifying and preserving these indispensable benefits must be a priority. Sustainably harnessing insects' multifunctional contributions will be key to resilient food systems and economies.

## 3. Major Insect Pests

Among the more than one million known insect species, approximately 10% are agricultural pests responsible for substantial crop losses worldwide [5, 16]. Major pest groups threatening global food security include insects that attack staple grains, horticultural crops, and stored agricultural products post-harvest. Cereals like maize, rice, sorghum, and wheat provide over 50% of humanity's food calories and nutrients [3]. However, persistent pests like stem borers, armyworms, and locusts contribute to cereal crop losses averaging 18-26% globally based on 2008 data, with even higher regional losses [1]. For example, the African armyworm Spodoptera exempts caused total maize losses of $179 million USD across Southern Africa in the 2020-2021 outbreak [17]. Another voracious feeder, the fall armyworm *Spodoptera frugiperda*, spread from the Americas to invade Africa in 2016 and now affects millions of smallholder maize producers across 42 African countries [12]. Fungal pathogens like the devastating wheat rusts also constitute serious biotic threats. Modeling anticipates up to eight million tons of wheat lost annually to a highly virulent stem rust race, enough to feed 288 million people [18]. In rice, stem borers like *Chilo suppressalis*, *Scirpophaga incertulas*, and *Sesamia inferens* annually destroy over thirty million tons – food for more than 180 million people [16]. Post-harvest storage pests like *Sitophilus oryzae* further degrade stored rice and grains. Locusts routinely threaten rice harvests in Asia – a single swarm in Thailand consumed 1.3 million tons of rice in 1993 [2]. Globally, insect pests cause yield losses of 25-50% in rice when left uncontrolled [4]. Horticultural crops like fruits and vegetables are similarly menaced by diverse insect pests. Globally, an estimated 45% of fruit production is lost to pests like Tephritid fruit flies and mites [16]. Vegetables suffer up to 80% losses from pests, including aphids like the cotton aphid *Aphis gossypii*, Lepidopteran caterpillars, thrips, whiteflies, and viral phytopathogens they transmit [5]. These losses significantly impact availability and prices of fruits and vegetables critical for balanced nutrition. Additionally, 10-20% of grains and pulses are lost post-harvest to storage pests like *Prostephanus truncatus*, *Rhyzopertha dominica*, and *Callosobruchus chinensis* [16]. Aside from direct consumption, stored grains are crucial livestock feed; for example, nearly one-third of global maize production is used for animal feed. Storage pests therefore undermine food security on multiple fronts. Climate change is likely to exacerbate crop losses from many insect pests based on spatial modeling studies. Warmer temperatures may enable tropical pests like corn earworm *Helicoverpa zea* to expand poleward, threatening high-latitude cropping systems [1]. Similarly, scenarios estimate that rising temperatures could increase coffee berry borer *Hypothenemus hampei* infestations, compounding economic impacts in vulnerable tropical regions [19]. Overall, Deutsch et al. [1] estimated global crop losses to insects will increase 10-25% per degree Celsius of warming. Insect pests constitute a formidable and likely growing challenge to realizing global food security.

## 4. Negative Impacts of Insects

By causing substantial losses pre- and post-harvest across essential food crops, insect pests exact severe negative impacts constraining global food security. These include direct economic costs as well as secondary effects on trade, livelihoods, poverty, and ecosystems. Economically, the toll of crop losses from uncontrolled insect pests is staggering. Oliveira et al. [5] estimated the global value of crop losses to pests at over $470 billion annually as of 2001. Regionally, crop pests cost African nations up to $13.6 billion per year through the 1990s-early 2000s [2]. At a national scale, Brevault *et al.* [20] reported that fall armyworm inflicted over $1 billion in maize crop losses during its first invasion year in Nigeria. Individual farmers may lose entire crops or go into debt trying to replace losses, with severe consequences for household incomes and welfare [4]. As most farming worldwide remains small-scale, subsistence-oriented, these economic blows disproportionately impact poor rural households and exacerbate poverty [8]. Beyond direct losses, insect pests destabilize trade and labor markets through secondary impacts on crop values, yields, and quality. Wyckhuys and O'Neil [6] describe how whitefly infestations decreased Honduran tomato quality and volumes by 60%, causing short-term price spikes but long-term economic contraction as buyers sought alternative suppliers. Rural laborers and producers deprived of crop-related incomes likewise experience food access declines [21]. Evidence also links pest outbreaks to higher food prices and reduced food availability, inhibiting access especially for marginalized groups [22]. These complex economic disruptions undermine the stability of local food systems and food security. Environmentally, heavy insecticide use spurred by crop pests degrades ecosystems, including loss of beneficial pollinators and natural enemies through pesticide toxicity [23]. Eliminating natural biocontrol services forces continued pesticide inputs, incurring collateral damage like insect resistance and harmful residues in food and water [24]. Such ecosystem degradation carries a hefty cost - for instance, conserving wild insect pollinators at 2018 farm prices would save global agriculture over $160 billion annually [25]. Similarly, transitioning just 10% of insecticide use to biocontrol conservatively saves $8-20 per dollar invested [26]. Because robust ecosystems underpin sustainable crop production, environmental damage from intensive insecticide use ultimately undercuts long-term food security [7]. Socially, crop losses and financial instability from uncontrolled pests disrupt community welfare and cohesion. At the household level, peasant farmers confronting crop failures may turn to damaging coping strategies like accruing debt, removing children from school, or migrating for wage labor [6]. Those unable to recover slip further into poverty and food insecurity. Regionally, mass pest outbreaks that destroy crops and livelihoods trigger conflict over scarce resources while provoking waves of displacement [21]. The societal impacts thus span all levels, from families to entire regions. Insect pests profoundly undermine the productive capacity, economic vitality, ecosystem resilience, and social welfare essential for global food security. Integrated solutions balancing reduced crop losses and minimized ecological impacts are urgently needed. Promising strategies include enhancing farmer knowledge-sharing networks, improving pest forecasting and early warning systems, and expanding access to sustainable biological controls [4,8]. With proactive, evidence-based policies and collective action, the grave challenge posed by insect pests may be overcome.

## 5. Positive roles of insects

While undoubtedly destructive to crops and food security when unchecked, insects are far from universally harmful. Many insects play vital ecological roles underpinning sustainable food production. Others show promise as direct nutrition sources for humans and livestock. These positive contributions warrant greater recognition and integration into food system policies. Pollination services by insects like bees, wasps, butterflies, and flies are essential for 75% of globally important crop plants, including major staples like maize, rice, and wheat [23]. Animal pollination also improves production of fruits, vegetables, edible oil crops, and stimulant crops like coffee, enhancing dietary diversity and quality [22]. The economic value of this ecosystem service is correspondingly massive. For just five major crops in 2000, Gallai et al. [27] valued insect pollination's contribution at €153 billion. In Australia, managed European honeybees alone are estimated to add over $1.7 billion annually to crop production [23]. Insect pollinators powerfully bolster agricultural productivity and food availability worldwide. However, intensifying agricultural production has strained pollinator populations through habitat loss and pesticide exposures [21]. Declining pollination services threaten crop yields – for instance, cafeteria potato yields declined by up to 71% over a 20-year period as nearby wild bee diversity fell [28]. Reversing pollinator declines through creating foraging and nesting habitats within croplands can significantly boost food production. For example, Carvalheiro *et al.* [29] modeled that enhancing pollinator habitats across just 10% of European Union agricultural lands would raise pollinator abundance and crop production by at least half. Supporting healthy pollinator communities is therefore a tractable strategy for sustainably improving crop yields and food security. Insects also offer vital contributions below-ground by cycling nutrients, improving soil fertility, and boosting crop growth. Through consuming plant detritus and excreting nitrogenous wastes, insects like termites and scarab beetles enhance soil nutrient pools like carbon and nitrogen essential for plant growth [30]. By tunneling, insects aerate soils and redistribute nutrients deeper in the soil profile. These activities are quantifiably significant – earthworms and termites in tropical agroecosystems can replace annual nutrient inputs worth $340 per hectare [31]. With declining soil health threatening future crop productivity, leveraging insect nutrient cycling could reduce dependence on costly fertilizers [32]. Beyond pollination and soil health, insects offer great potential as direct nutrition sources through entomophagy – the practice of eating insects. Over two thousand insect species are consumed globally, providing energy, protein, fat, and vital micronutrients often lacking in poor diets [2]. Crickets, for instance, contain 12-25% dietary protein – more than soybeans [33]. Farming insects is also far more efficient than livestock like cattle – house crickets require just two pounds of feed to produce one pound of edible meat, compared to cattle's 10:1 feed conversion ratio [2]. As global meat consumption continues rising, insect farming could provide comparable nutrition with reduced environmental impacts [15]. Although entrenched stigma constrains adoption in some societies, integration into familiar foodstuffs like fortified flour helps normalize insect consumption and improve nutrition [34, 35]. With visionary public policies, entomophagy could meaningfully augment global food security.

## 6. Impacts of insect pests on food security in low- and middle-income countries

Insect pests pose outsized risks to food security in low- and middle-income countries, where agriculture remains crucial for livelihoods and hunger persists for millions. These impacts manifest in various ways, contributing to a cycle of poverty and food insecurity. Insect pests can cause significant crop loss and yield reduction, leading to economic losses for farmers and compromising food quality, safety, food shortages and malnutrition. The extent of these losses varies across regions, with higher losses observed in the developing tropics of Asia and Africa [36]. Global warming and climate change exacerbate the problem by triggering changes in insect populations, distribution, and behavior. Rising temperatures and changing cropping patterns may lead to increased damage by major insect pests in staple crops. Sub-Saharan Africa exemplifies the vulnerabilities; the region depends on staple grains like maize and sorghum, which face persistent yield losses from endemic pests like stem borers and new invasive species [37]. Post-harvest storage losses are also severe - ranging from 15% for maize to 60% for cowpeas - due to lack of infrastructure and pests like the larger grain borer [3]. Regionally, fall armyworm inflicted around $3 billion in direct crop damages during its 2016 arrival, revealing how new invasive pests can destabilize food systems [38-40]. At a household level, crop loss impacts reverberate through interconnected outcomes like income decline, food insecurity, diminished health and education access, and dangerous coping strategies that perpetuate poverty [41-44]. Socially, locust outbreaks in 2020 sparked community resource conflicts in East Africa, while West African cacao farmers resorted to child labor to combat swollen shoot virus spread by mealybugs [44-48]. Such complex impacts reveal differential pest pressures facing smallholder agricultural systems in developing regions. Though locally adapted ecological management approaches can help strengthen resilience, sufficient political will and resources must be directed to this problem affecting millions of vulnerable rural livelihoods. The food security stakes could not be higher. In clear, realizing sustainable global food security in coming decades represents an immense but imperative challenge. With crop losses to insect pests estimated at 18-26% of global production worth nearly $500 billion yearly, these agricultural antagonists pose a formidable constraint [1,5]. However, insect pollination, soil nutrient cycling, and value as food also highlight the possibilities of balancing productivity with stability. What strategies then can maximize benefits while minimizing harm from these tiny but impactful organisms? First, integrated pest management (IPM) approaches leveraging cultural, biological, and judicious chemical controls can suppress pest populations while curtailing ecosystem damage [8]. Practices like crop rotations and intercropping make habitats less suitable for pests while enhancing natural enemies [4]. Timely field scouting, forecast modeling, and rapid sharing of pest sightings through farmer networks also enable earlier, targeted responses [12]. Although pesticides remain useful tools, practices like using reduced or targeted applications can retain efficacy while lowering ecological impacts [6]. Community-based programs to promote such IPM methods show promise for balancing productivity, profitability, and sustainability [42]. For example, FAO-supported farmer field schools (FFS) provide hands-on, peer-based IPM education at the village level [49]. Meta-analysis found that across Asia and Africa, FFS graduates reduced insecticide use by over 50% while sustaining or increasing yields, highlighting the viability of ecologically based pest control [50]. To succeed, programs must consider farmer circumstances, constraints, and knowledge to ensure appropriate, locally adapted solutions [26]. Second, stabilizing the ecosystem processes underpinning agriculture is critical to enable sustainable production [7]. Prioritizing pollinator health through practices like interspersing native flowering plants will boost crop yields and offset losses from pests [29]. Similarly, adopting reduced tillage and other conservation agriculture methods retains soil structure to support beneficial insects [32]. Agroecological methods that thoughtfully integrate ecological principles and diverse biological interactions can suppress pests through system resilience rather than intensive external inputs [51]. While transitioning to such ecological production systems requires time and appropriate technical assistance, long-term food security obligates this shift. Lastly, policy and governance dimensions are essential to scale suitable solutions and align actors in the shared cause of sustainable food security. Governments should increase investments in extension services and farmer education in IPM and agroecology [8]. Regional coordination can improve pest forecasting, surveillance, and rapid response, such as Africa's Fall Armyworm Monitoring and Early Warning System [20]. Standards and procurement policies to reward ecologically-sound practices would provide market incentives for adoption (FAO, 2013). Ultimately, inclusive, informed, and integrated policy environments can empower communities to control pests while conserving the ecosystems on which agriculture depends.

## 7. Recommendations to maximize the positive economic impacts of insects on food security

- Invest in research and development for insect farming systems. Optimizing rearing and processing methods to increase yields and efficiency can help scale up production to commercial levels for human food and animal feed uses [15].
- Provide incentives and policy support to grow the edible insect sector. Tax credits, grants, and standards can encourage industry growth. Government promotion programs can also increase public acceptance and consumption [2].
- Facilitate use of insect ingredients in processed foods and feeds. Allowing uses like enriched flours and protein powders enables insects to supplement nutrition in familiar, accessible products [51].
- Promote sustainable wild harvesting from some edible insect populations. Developing fair trade standards and practices can supplement farmed supplies while providing livelihoods [35].
- Increase farmer training and access to biological pest control. Building capacity in methods like habitat provision, conservation biocontrol, and use of biopesticides leverages natural ecosystem services for sustainable plant protection [6].
- Mainstream agroecology and integrated pest management (IPM). These ecological approaches support beneficial insects that enhance production and reduce reliance on pesticides [52].
- Preserve and restore insect habitat in agricultural landscapes. Hedgerows, wildflower strips, and diverse cropping patterns sustain pollinators and natural enemies to boost productivity [53].
- Improve regional monitoring, forecasting and management of migratory pests. Coordinated early warning and rapid response to outbreaks minimizes losses and ecological damage [12].
- Develop insect-based commodities like dyes, waxes, and silk. Creating additional income streams increases sustainability for farmers while meeting consumer demand [51].
- Raise public awareness of insects' multifunctional benefits. Outreach and education address misperceptions, increase acceptance, and enable advocacy to influence policymaking [54].

## 8. Recommendations minimize the negative economic impacts of insect pests on food security along with relevant references

- Adopt integrated pest management (IPM) approaches that balance multiple controls. IPM utilizes practices like biocontrol, habitat management, and judicious pesticides that reduce ecological damage and resistance [55]. It's clear that traditional pest management often relied on the use of chemical pesticides, which had detrimental effects on non-target species and the environment. However, an innovative approach in recent years involves ecological pest management strategies that aim to minimize ecological disruptions while effectively controlling pests. This includes employing natural predators, implementing crop rotation, utilizing trap crops, and embracing integrated pest management (IPM) principles. IPM combines biological, cultural, and mechanical control methods with limited pesticide use, emphasizing an integrated approach that is environmentally sustainable. Lastly IPM reduces reliance on pesticides while keeping pests below damaging levels [56].
- Prioritize agroecological farming systems that promote biodiversity. Diverse farms support natural enemies, boost ecosystem services, and increase resilience to pest outbreaks [52]. It shows that diverse farms with multiple crops and habitat types support more natural pest enemies, boost pollination and other ecosystem services, and increase resilience to pest outbreaks compared to monocultures. Promoting biodiverse agroecology involves transitioning away from chemical-intensive monocultures toward ecological practices like crop rotation, polycultures, habitat conservation, and animal integration. This

provides environmental benefits like reduced pollution and carbon sequestration while supporting sustainable food production.

- Improve monitoring, forecasting, and rapid response capacity for migratory pests. Robust surveillance networks and coordination enable early control before widespread crop losses [12]. So, Improved monitoring, forecasting, and rapid response capacity for migratory crop pests should be developed. This involves consistent regional monitoring, forecasting models utilizing weather data and habitat maps, stockpiled resources for rapid response, and coordination between government agencies and international organizations. Investing in these systems allows early detection and quick containment of destructive pests as they move between regions, reducing agricultural losses.
- Develop and disseminate pest-resistant crop varieties through conventional and biotech breeding. Resistant varieties reduce reliance on pesticides while protecting yields [4]. Developing and disseminating pest-resistant crop varieties can be achieved through conventional breeding methods as well as biotechnological interventions [57, 58] Conventional breeding involves techniques such as selection, hybridization, and backcross methods of gene transfer Priyanka [59, 60]. Biotechnological techniques, including new generation nucleases and CRISPR-Cas, along with conventional mutation breeding and genetic transformation, can provide significant advancements in crop breeding [61]. These approaches can help exploit natural genetic variations and create new gene pools for improved crop traits [61-71]. Additionally, the use of resistant cultivars, combined with other pest management methods such as natural enemies, cultural practices, and physical barriers, can effectively control pest populations, and reduce the need for insecticides. Collaborations with various experts, including social scientists, economists, and virologists, are necessary to integrate insect-resistant plants into integrated crop pest management programs.
- Support farmer organizations and knowledge-sharing networks. Peer learning and collective action strengthens adaptive capacity and access to IPM innovations [42].
- Provide financial safety nets *via* insurance, credit, and savings programs. Risk management tools prevent harmful coping strategies and enable recovery after pest-related crop failures [8].
- Invest in post-harvest storage and handling infrastructure. Reducing storage losses to insects maintains food supplies and income [59]
- Diversify smallholder livelihoods beyond crop production. Alternative income from livestock, crafts, etc. provides buffers during crop losses [24].
- Develop value-added processing of damaged crops into feeds, biofuels, etc. Innovative uses reduce economic losses and waste [37].
- Raise consumer awareness to reduce food waste and overconsumption. Lower per capita waste reduces production needs and resources consumed globally [56].

## 9. Conclusions

Insect pests are a persistent threat to food security, but their economic impacts on vulnerable populations can be minimized through ecologically based, socially-just pest management approaches. This review synthesizes evidence supporting integrated practices at the farm level, improved monitoring and response to migratory pests, resistant crop development, farmer support networks, safety nets, and post-harvest storage investments. A mix of technological, organizational, and policy measures across food systems is required. Transitioning to biodiverse, resilient agroecological production, while raising consumer awareness, has great potential to reduce producer and consumer sensitivity to pest-induced losses.

### Recommendations

Key recommendations include increasing public and private investment in agroecological research, strengthening farmer organizations, developing forecasting capacity and emergency response plans for migratory pests, expanding access to financial services and crop insurance for smallholders, and launching consumer education campaigns to reduce food waste.

### Future Research

Further research is needed to quantify the efficacy and costs/benefits of recommended approaches in localized contexts. Evaluations of farmer knowledge exchange networks, safety net programs, and post-harvest storage innovations will support implementation and scaling. Continued research on breeding for pest resistance, ecological pest suppression, and early warning systems is warranted, along with research on farmer decision-making and consumer behavior to support adoption of socially optimal solutions.

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### Competing interests

The authors declare that there are no competing interests.

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