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Review Article

Integrated Pest Management (IPM) in Agriculture and Its Role in Maintaining Ecological Balance and Biodiversity

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The production of sustainable crops and environmental management in farming face several significant potential obstacles, including climate change, resource depletion and environmental degradation. Weeds and insect pests that considerably reduce yields have put crop production systems in danger. The greatest worry for farmers is the decline in productivity due to illnesses and pests. Insects, weed pests, and plant pathogens destroy more than 40% of all potential food production every year. The widespread use of integrated pest management (IPM) is a result of worries about the long-term viability of conventional agriculture. IPM ensures sufficient, secure, equitable, and steady flows of both food and ecosystem services, as well as increased agricultural profitability due to lower pest management expenditures. A number of studies conducted on IPM have been combined. Important information from all these studies was analyzed and summarized in this literature review. In this article, we investigated the following: (1) explanation of different management components; (2) development in organically integrated weed and insect pest management, with possible ramifications and scope; (3) knowledge and adaptation status of IPM in the modern world; (4) resources and tools of IPM; (5) current challenges and suggested future research priorities. Regular training related to IPM should be arranged to spread the knowledge of IPM to all farmer levels. This requires the cooperation of the government. Furthermore, IPM will reach a new milestone if Internet of Things technology is practiced along with the existing pest control method. Overall, this review addresses the possibilities for researchers and farmers to use a variety of natural control agents as a full or partial replacement for synthetic pesticides.

1. Introduction

A challenge to achieving global food safety and sustainable development is posed by pathogens, weeds and insects since they significantly reduce agricultural yields globally [1]. Yield losses caused by pests may be equivalent to the amount of food needed to feed nearly 1 billion individuals when considered in terms of food security [2]. Alternative means must be used to limit pest damage while avoiding the expense and unfavorable effects associated with synthetic pesticides. However, excess use of these pesticides brings additional obstacles, and it is now obvious that they must be avoided.

Integrated pest management (IPM) involves the use of several pest control techniques intended to supplement or completely eliminate the use of synthetic pesticides. It has been used for a very long time and is a sustainable pest management method [3]. By applying IPM, pest populations are kept below a point where they cannot harm the economy [4]. It involves determining strategies that are practical, affordable, and minimize environmental damage [3]. IPM refers to the management of crops using a variety of strategies to keep pest levels below a certain economic threshold [5]. It is a methodical strategy that incorporates many pest-control measures into one program. Incorporating cultural, biological, genetic, physical, legislative and mechanical constraints lessens the dependence on pesticides [6]. A sustainable food supply would be ensured through an integrated weed management plan that includes diverse chemical, cultural, physical, and preventative weed control strategies. Agronomic weed control is unquestionably a component of integrated weed management strategies, and the producer's set of cultural techniques—such as crop density, the use of difficult varieties, or strategic mineral fertilizer planning—can easily manipulate this component. When using herbicides is not an option, this is particularly true [7].

We emphasized the value of IPM in improving crop productivity and gave particular attention to various management techniques in this review. We discussed the development of bio-based integrated insect pest and weed management in agricultural crop production, as well as any potential ramifications and scope. In addition, we discussed the status of knowledge and adaptability, as well as the resources and tools of contemporary IPM. This study also identifies current limitations and upcoming requirements to enhance IPM use in contemporary agriculture. In actuality, the main goal of this review is to explain cutting-edge methods that farmers can employ to maximize the use of diverse natural controls as an alternative to synthetic pesticides.

2. Methodology

To study the function of IPM in agriculture to preserve ecological balance and biodiversity, extensive scientific databases were examined for pertinent material and citations. Google Scholar, Web of Science, Springer Link, Wiley Online Library, and Mendeley were used to search the scientific literature. We used the keywords "Integrated Pest Management," "IPM," "biodiversity," "ecological balance," "IMP adoption," "physical control," "cultural pest control," "chemical control," "biological control," "entomopathogen," "IoT in pest control," "drone in IPM," "pest monitoring," "pheromone," "microorganism involved in IPM" for finding related papers. We chose some research and review articles based on some selected criteria. The selection criteria were (i) the study includes the relationship among IPM, ecological balance, and biodiversity; (ii) the study includes the role of fungus, viruses, nematodes, predators, and other microorganisms in IPM practices; (iii) the study includes different pest control techniques in IPM; (iv) the study includes the adaptation status of IPM; (v) the study includes the role of Internet of Things (IoT) and drones in pest control. In this study, an effort has been made to consolidate all available material on IPM strategy, including management components, adaptation approaches, resources, and tools of IPM, as well as present difficulties and potential scope for preserving ecological balance and biodiversity. This review has compiled a total of 143 references, including research articles, books, and reviews from 1997 to 2023. In the current review article, seven tables and two figures have also been added based on the synthesis of the references gathered to present various types of insect pest predators and parasitoids, entomopathogenic microorganisms and their target pests, physiological impact of some allelochemicals on insects, management of agricultural insect pests with physical control methods, pathogenic fungi, nematode species, viruses and bacterial species with their target organisms, Percentage of IPM training received and nonreceived by farmers and framework of IPM adoption. The figure is drawn using the software "Microsoft PowerPoint 2019," and the pie chart is from "Microsoft Excel 2019". The PRISMA outlined the techniques for screening previously published papers collected from databases (Figure 1).

3. Historical Background of IPM

Beginning in the 1970s, in response to rising awareness of the negative side effects of pesticide use, the concept of "Integrated Pest Management" was first introduced in agriculture. The strategy emphasizes combining artistic techniques with pest biology to control insect pests in crops [8]. A thorough experiential learning strategy, like farmer field schools, is needed to assist farmers in fully comprehending the applications and implications of IPM because it is a complicated technology [9]. It has been 50 years since pest management research in some regions of Europe, Canada, and the United States focused on developing threshold theory and harmonic control tactics [10]. The majority of cultural, mechanical, genetic, chemical, and biological techniques are incorporated into IPM strategies and measures to maintain the number of dangerous pests in a crop below the threshold that would result in an economic loss [11].

The spotted *Alfalfa aphid* and the *Alfalfa caterpillar* were the first pests for which early "supervised" and "integrated" management schemes were created. IPM has since been described as the predominant crop protection paradigm, but adoption rates are still modest [12, 13]. Due to people moving to new locations within or across nations and the globalization of the food industry, more pest species have been introduced into areas where they did not previously exist. IPM's gradual expansion in popularity has led to increased recognition of it as an ecologically sustainable strategy that can also ensure the output and quality of agricultural goods [14]. IPM, then, may be defined as the adoption of a superior pest management method that reduces agricultural yields while minimizing chemical toxicity to the beneficial organisms that are essential to the success of the actual management practice [11].

Currently, countries in Africa and Latin America are using integrated production and pest management together and concurrently [11]. The central tenets of IPM are (a) encouraging healthy soil and crops, (b) fending off natural predators, (c) frequently monitoring crop health and pest activity, and (d) imparting technological expertise to the farming society. IPM strategies expand on these needs to combine the ability to control the behavior of numerous insects that are detrimental to agricultural production with enhanced environmental conservation due to reduced chemical pesticides [14].

4. Management Components

4.1. Genetical Control. The many constitutive and inducible defense mechanisms that plants have evolved to thwart insect attacks are called resistance in host plants. A complicated web of interactions is involved in the research on host plant resistance, and these interactivities are mediated by chemical and morphological characteristics that affect how

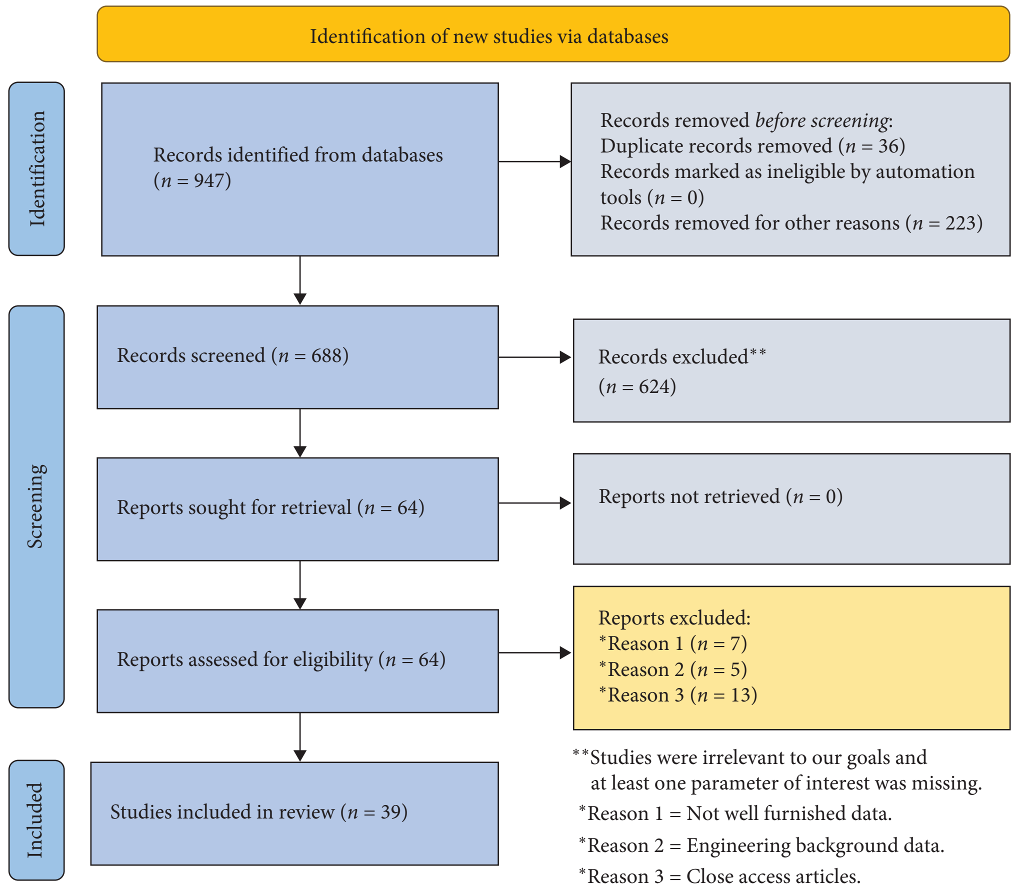

Figure 1: The PRISMA diagram depicts the search, screening for inclusion, exclusion, and accepted studies for the IPM review.

much harm pests do [15]. Multiple resistance characteristics may exist, including antixenosis and antibiosis resistance [16]. They are categorized as constitutive resistance (preexisting in the plant prior to the raid), induced resistance as a result of *Tuta absoluta* infection, or genetically inserted resistance [17]. A tactic that takes advantage of cultivars created through genetic engineering [18]. These cultivars feature physical, biochemical, or morphological characteristics that make them less attractive to pests or less favorable to their growth, development, or successful reproduction.

4.1.1. Morphological Structures. A host plant's surface may act as a physical barrier due to morphological characteristics like waxy cuticles and/or trichome-like epidermal structures [15]. The natural enemies of pests are allured to and rewarded by indirect defenses, which employ them as "bodyguards." Plant characteristics that aid in indirect defense include smells (frequently caused by pests), which draw natural enemies to afflicted plants [19], and nectar that holds down and remunerates attracted natural enemies of pests [20].

4.1.2. Chemical Host Plant Resistance. According to a study on various chrysanthemum types, isobutyl amide may be linked to host plant resistance to the western flower thrips. By creating an ecometabolomic method and assimilating the metabolomic profiles of resistant and susceptible plants, compounds for constitutive western flower thrips resistance were found and validated in subsequent in vitro bioassays [21]. *Jacobaea vulgaris* (a wild plant species) had jacobine, jaconine, and kaempferol glucoside; chrysanthemums included chlorogenic and feroluylquinic acids; tomatoes contained acyl sugars; and carrots contained alanine, sinapic acid, and luteolin [21, 22].

4.1.3. Transgenic Plant. The majority of transgenic crops resist pests that are lepidopteran and/or coleopteran, or maybe even a mixture of both features, such as glufosinate-ammonium, glyphosate, 2–4 D, dicamba [23]. For instance, cotton, maize, soybean, sugar beet, alfalfa, and canola all possess herbicide-resistant characteristics that bestow glyphosate tolerance [24]. Cotton [11], soybean (lepidopteran pests) and maize [25] all possess insect defenses that, until now, were mostly given by insecticidal proteins gleaned from *Bacillus thuringiensis* (Bt) (lepidopteran and coleopteran pests). Since 2014, a Bt trait for a lepidopteran pest has been found in aubergines in Bangladesh [23].

4.1.4. Induced Resistance. Several plant regulators salicylic acid (SA), jasmonic acid (JA) and ethylene (ET), together with other chemicals that occur naturally in reactions, defend plants from infections and insects [26]. The JA pathway is an important part of the defense against thrips. When thrips were introduced to Arabidopsis plants, the JA-responsive genes VSP2 and PDF1.2 became very active.

4.1.5. Plant Vaccination. When a pest attacks a plant, it typically responds by activating both immediate and indirect defenses, successfully repelling both the pest that is attacking at the time and pest species that may attack in the future [27]. If the organism that induces defense is nearly benign and the plant is derived to become immune by the induced defense to a more harmful pest, this procedure can be referred to as "plant vaccination" [26]. Plants can be protected against pests and pathogens by being exposed to elements that cause them to enter a "primed" state [28].

4.2. Cultural Control. The deliberate modification of a farm or garden for the purpose of growing and cultivating plants to reduce plant disease and various pest attack is known as a cultural method. Evidence for this exists: the effective application of cultural approaches to managing soilborne pathogens results in enhanced soil structure and lower disease prevalence [29]. Crop rotation, the timing of planting, a change in crop variety, irrigation management, harvesting, and utilizing trap crops are other cultural practices used in agricultural crops that are more preventive than curative and may thus need advanced preparation. Cropping techniques like alley cropping, intercropping, strip cropping, mixed cropping, etc., when used with caution, can serve as a deterrent, danger, or concealment for pests. In the limited intercropping studies that examined oilseed rape (*Brassica napus* L.) insect pest responses

Legume intercrops lessened damage from the cabbage stem weevil (*Ceutorhynchus pallidactylus*) and rapeseed winter stem weevil (*Ceutorhynchus picitarsis*) [30]. Also, powdery mildew (caused by *Podosphaera aphanis*) and botrytis fruit rot (caused by *Botrytis cinerea*) were often less severe in strawberry plots with microsprinklers than in strawberry plots with overhead aluminum sprinklers. The crop rotation between marsh rice and upland maize has an impact on the bacteria and archaea that colonize roots [31]. Plowing is another crucial preventative measure to get rid of crop debris and reveal the stages of various vegetable pests that live in the soil [32]. Cultural interventions can take a lot of time and effort and are usually preventative [33].

4.3. Biological Control. The use of natural enemies to manage weeds, illnesses, and insects is defined as biological control [34]. Although it has limitations depending on how it is utilized, augmentative biological control with repeated releases only briefly lowers pest outbreaks, and few programs achieve permanent control. The effectiveness of using biological control using evolved extractions varies depending on how it is used; however, few programs are able to permanently suppress pest outbreaks [35]. In some cases, the presence of natural enemies such as parasitic wasps and predatory arthropods can significantly reduce pest numbers [36], and some typical approaches for controlling endemic pests include the regular release of commercially available natural enemies, the protection of natural enemy populations by providing refuges or avoiding acts that harm them [3].

4.3.1. Predators. Asopinae (Heteroptera: Pentatomidae) stinkbugs, which eat other bugs, are important for keeping an eye on a variety of pests, such as lepidopteran larvae in greenhouses and fields and herbivorous pentatomid species (Table 1) [37]. Predatory insects are exploited in integrated pest control systems, including lacewings, ground beetles, centipedes, dragonflies, rove, midges, ladybugs, pirate bugs, and aphids [38]. *Anystis baccarum* (L.), a generalist predatory mite, was created in Canada as a new biocontrol agent and went on sale in 2022 [39]. Lady beetles are voracious eaters and may be common in areas where food is plentiful, and broad-spectrum pesticide use is prohibited. Lady beetles are excellent predators when aphids are plentiful (high pest density), but they are thought to be less effective when pest consistency is low [40].

4.3.2. Parasitoids. Insect pests are specifically targeted by parasitoids, a type of natural enemy. Unlike true parasites, parasitoid organisms kill their prey and complete their development on a single host [42]. Lepidoptera, Coleoptera, and Neuroptera represent a small minority of the parasitoids, which are typically Diptera or Hymenoptera. In contemporary decades, the parasitoids of the families Bethilidae, Braconidae, Ichneumonidae and Pteromalidae have sparked a surge in interest in parasitoid-based biological management of stored goods pests [43].

4.3.3. Entomopathogens. Bacteria and fungi that grow inside plant tissues without manifesting any disease signs in the host plant are referred to as endophytes. It is vital to highlight that while fungal endophytes are common in plant species, their features and degree of colonization vary depending on the kind of plant tissue [44]. Several research studies have revealed that entomopathogenic fungi (EPF) are effective against insect and mite pests. They also enhance the plant's ability to respond to other biotic stresses [45]. During several biocidal actions, substances like insecticides, antifungals, herbicides, and antivirals are produced, which causes systemic resistance to be induced [46]. Because they can infect insects directly through the cuticle, EPF, a key group of biological control agents for pests with chewing mouthparts, like whiteflies and other sap-sucking pests, play an important role in the natural decline of whitefly populations [47]. There are about 700 species of EPF, which are members of the groups Laboulbeniales and Pyrenomycetes (*Ascomycota*, *Deuteromycota*) (Table 2) [48]. EPF is a superior alternative that can be exploited to manage many species of ticks, mites and insects since they can infect insects through their cuticles before the disease is caused by ingestion [49]. Additionally, it has been demonstrated that they can almost entirely stop insects at all phases of their life cycles, making them one of the key components of IPM strategies [50].

4.4. Behavioral Control. Assorted traps are treated in the field not only to enthrall the pests but also to cut down their offspring by shattering their mating capability, such as baits containing poisons, color traps, light traps, pheromone lures, etc. [3]. A good illustration of a technology created by academics and now employed commercially by American

Table 1: Some insect pest's predators and parasitoids [41].

Stages attacked	Predators of-			Parasitoids of-		
	Crickets	Leaf folders	Brown planthopper	Yellow stem borer	Leaf folders	Brown planthopper
Egg	*Conocephalus longipennis*	*Conocephalus Longipennis*, *M. vittaticollis*, *Cyrtorhinus Lividipennis*, *Reuter*, *Micraspis crocea*, *Mulsant*	*Cyrtorhinus lividipennis*	*Trichogramma Japonicum*, *Tetrastichus Schoenobii*, *Telenomus rowani* (Gahan), Ashmead, Ferriere	*Copidosomopsis Nacoleiae*, (Eady), *Trichogramma Japonicum*, (Ashmead)	Anagrus spp., Oligosita yasumatsui, (Viggiani and Subba Rao)
Larva	*Micraspis* spp., *Lycosa pseudoannulata* (Boesenberg and Strand), Ants, *Ophionea* spp., *Microveli douglasi Atronlinea*, *Mesovelia vittigera*, *and Limnogonus fassarum* (*F.*)	*Ophionea spp*, Water bugs, *Lycosa pseudoannulata*, Ants, *Micraspis* spp.	*Synharmoni octomaculata* (*F.*), *Lycosa Pseudoannulata*, *Paederus fuscipes Curtis*, *Cyrtorhinus lividipennis*, *Migrovelia douglasi atrolineata Bergroth*	*Bracon chinensis*, Szepligeti, *Temelucha philippinensis*, Ashmead, *Stenobracon nicevillei* (Bingham)	Uchida, *Trichomma enaphalocrosis*, Cotesia augustibasis, *Temelucha philippinensis*	*Pseudogonatopus* spp.
Pupa	Also attacks adults		*Paederus fuscipes Curtis*, *Synharmoni octomaculata*	*Tetrastichus ayyari*	*Tetrastichus ayyari*, *Xanthopimpla*, Flavolineata Cameron, Rohwer	*Pseudogonatopus* spp.

Table 2: Common entomopathogenic microorganisms and their target pests [51].

Target pests	Entomopathogens
Acarina, Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Orthoptera, Thysanoptera, and other pests nematodes that parasitize plants	**Fungi**—*Hirsutella thompsonii*, *Isaria fumosorosea*, *Lecanicillium lecanii*, *L. longisporum*, *Metarhizium anisopliae*, *M. brunneum*, *and Paecilomyces lilacinus*
Lepidoptera	**Viruses—Nucelopolyhedrovirus (NPV)***Spodoptera exigua* NPV*Helicoverpa zea* NPV**Granulovirus (GV)***Cydia pomonella* GV
A number of orders of soil-borne pests	**Nematodes**—*Steinernema carpocapsae*, *H. heliothidis*, *S. feltiae*, *S. carpocapsae* and *Heterorhabditis bacteriophora*
Lepidoptera Diptera Lepidoptera Coleoptera Japanese beetle	**Bacteria**—*Paenibacillus papillice*, *Bacillus thuringiensis subsp. aizawal*, *Bacillus thuringiensis subsp. israelensis*, *Bacillus thuringiensis subsp. Kurstaki*, *and B. thuringiensis subsp. tenebrionis*.

Table 3: The physiological impact that some allelochemicals have on insects [60].

Physiological or behavioral effects	Responsible allelochemicals
Bring about physiologic imbalances, whether chronic or acute	Toxins
Obstruct the use of food by interfering with the processes	Digestibility reducing
Imprison insects	Arrestants
Minimize oviposition or feeding	Deterrents
Refrain from biting or piercing	Suppressants
Move more quickly	Locomotor excitants
Encourage insects to avoid the plant	Repellents
Give generating organisms a competitive advantage through adaptation	Allomones

blueberry growers is a mating disruption for oriental beetles; a microencapsulated sprayable formulation, point-source dispensers (bubbles), and a sprayable formulation using Specialized Pheromone and Lure Application Technology have all been studied [52].

4.4.1. Pheromones. Some creatures generate "sex pheromones," which are chemical signals that trigger a sexual response in a member of the same species' opposite sex [53, 54]. In contrast to pheromones, which are chemical messengers involving male and female adults of a species of insect, which one sex uses them to communicate with its sex partners the proneness and assent to mate [55]. The sex pheromones of prominent lepidopteran pests such as tomato fruit worms (*Helicoverpa armigera*) and common armyworms are commonly used as surveillance attractions in tropical vegetable production systems (*Spodoptera litura*) [56]. In a Japanese tea plantation, sex pheromones were investigated as potential mating-disruption agents against *Ascotis selenaria cretacea* (Butler) [57].

4.4.2. Allelochemicals. Allelochemicals are nonnutritional chemical compounds that an organism or plant secrets into the surroundings and which cause a particular reaction in a different species [58]. In an effort to find a multifunctional pesticide for use in IPM, different allelochemicals were tested for their capacity to control weeds and fungi [55]. Allelochemicals include aldehydes and ketones, pyrethrum, alkaloids, glycosides, glucosinolates, limonoids, quassinoids, saponins, organic acids, piramides, polyacetylenes, polyphenols, terpenes, phenolics, flavonoids and quinones, which are naturally found in various plant components and protect plants from different types of pests (Table 3) [59].

4.5. Physical Control. Recent developments in pesticide resistance, the desire to eliminate chemical residues, and practical considerations have made physical control of insect pests more popular. Physical control involves altering the environment so that pest insects cannot live or grow there. Physical methods can be passive or active. Passive methods include hermetic storage, packaging, air doors, screening, etc., while active methods include inert dust, sieving, and temperature modification (aeration treatments, heat, grain chilling, etc.), and electromagnetic methods (microwaves, radio frequencies and ionizing radiation). Active techniques require ongoing input during the control period to be effective. The quantity and intensity of the input affect the degree of control attained. From emergence to postharvest, plants are well-protected by physical management techniques. Physical control techniques are better adapted to postharvest settings since the environment is somewhat limited, the substance has great economic value, and insecticide application is typically inappropriate or even prohibited. In postharvest quarantine situations where a specific pest's infestation must be eradicated at a certain level of control, physical control techniques like ionizing radiation,

Table 4: Management of agricultural insect pests with physical control method.

Sl. no.	Scientific name	Specific physical management techniques	References
1	*Aleurodicus dispersus* (Spiralling whitefly)	Whitefly nymphal and pupal phases can be controlled by yellow sticky traps and leaf removal	[61]
2	*Myzus persicae* (Aphid)	Detracts from the appeal of hosts	[62]
3	*Chilo partellus* (Stem borer)	Successful treatment of stem borer is achieved using the push-pull technique	[63]
4	*Bactrocera dorsalis* (Oriental fruit fly)	Fly can be controlled using a pheromone trap with methyl eugenol	[64]
5	*Liriomyza sativae Bonagota salubricola*	Fruit bags for control	[65]
6	*Thrips tabaci* (Onion thrips), and *Bemisia tabaci* (Whiteflies)	The use of floating row covers and white nets to control the population	[66]
7	*Papilio demoleus* (Lemon butterfly)	White nets and floating row covers help the lower population and successfully manage. Destruction of the several butterfly phases and hand-picking of the adults	[67]
8	*Spodoptera litura* (Tobacco cutworm) *Phyllocnistis citrella* (Leaf miners)	Hand-picking without the use of control techniques	[68]
9	*Aonidiella aurantii* (Scales) *Phyllocoptrata oleivora* (Mites)	Mineral oils have a strong ability to exert control	[69]
10	*Batocera rufomaculata* (Mango stem borers)	Using nylon mesh to cover stems from May to August makes it easier to catch newly emerged adult beetles	[70]
11	(Whitefly) *Bemisia tabaci*	Using nylon net as a physical barrier to reduce whiteflies in chili	[71]
12	(Sweet potato whitefly) *Bemisia tabaci*	Effective physical barrier: free-floating coverings	[72]

heat, and cold are frequently used. Some specific physical management techniques are highlighted in Table 4.

4.6. Microbial Control. Addressing the problems caused by numerous pests is essential for sustainable agricultural production. These pests include birds, animals, weeds, fungi, viruses, nematodes, and insects. As an environmentally acceptable strategy for pest population management in the agricultural sector, microbial pesticides are extremely acceptable and ideal for academics and farmers [73, 74]. Currently, many microbial biopesticides have been created from fungi, bacteria, viruses, nematodes, and protozoa and are employed in insect pest management techniques worldwide [75]. Microbial pesticides are gaining popularity due to their lower environmental toxicity, target specificity, and safety for non-target organisms [76, 77].

4.6.1. Viruses. Lepidopteran caterpillars, which consume insect pests, are subject to control by microbial biocontrol agents found in a variety of entomopathogenic viruses. *Baculoviruses*, DNA viruses with double strands, infect and kill a wide variety of insect pests [78]. On a variety of crops, recent studies have shown a considerable decrease in disease severity for a range of pathogens, including *Streptomyces*, *Agrobacterium*, *Xanthomonas*, *Erwinia amylovora*, and *Ralstonia solanacearum* (Table 5). Phage use has the following benefits: (a) simple manufacture; (b) good selectivity for the target organism; (c) lengthy shelf life. To spread the phage in the field, the crop might be dressed with an avirulent variant of the pathogen that is infected with it. Even though it cannot harm the crop, the avirulent strain acts as a conduit for the phage's production [79].

4.6.2. Bacteria. Bt is one of the most effective and widely utilized microbial control agents, having been found to contain more than 240 holotypes of cryotoxins that are active against Lepidoptera, Diptera, Coleoptera, and Hymenoptera [82]. Bt is one of the more than 100 bacterial species that have been recognized as microbial agents against insect pests [83]. *Burkholderia*, *Pseudomonas*, *Serratia*, *Saccharopolyspora*, *Chromobacterium*, *Bacillaceae*, *Yersinia*, and *Streptomyces* species are among the entomopathogenic bacteria, whereas different strains of the fungi—*Metarhizium anisopliae*, *Hirsutella*, *Isaria*, *Beauveria bassiana*, *Paec Baculoviruses*, *Lecanicillium* are species-specific insect pathogenic viruses that attack insects by biting and chewing, especially lepidopteron caterpillars (Table 5) [73, 84].

4.6.3. Fungi. The microbial pest management technique heavily relies on pathogenic fungi, which can be both terrestrial and aquatic (Table 6). Those fungi that coexist closely with insects are referred to as EPF. These relationships can take the forms of commensalism, symbiosis, and parasitism and are typically voluntary or required [85]. Because of their potential as biocontrol agents, fungal infections of insects have recently attracted increased research. In that sense, numerous fungi have been discovered to be pathogenic to insects after being tested for virulence against insects. Over 750 fungal species, primarily from the entomophthorales and hyphomycetes, are harmful to insects, and many of them have tremendous promise for pest control [86]. *Metarhizium anisopliae* is currently being used as part of the largest single microbial control effort employing fungus to eradicate spittlebugs (Cercopidae) from South American sugarcane and pastures [87].

Table 5: Some important viruses and bacterial species with their target organisms [80, 81].

Virus	Target insect	Bacteria	Target insect/pest
Pox virus	*Amsacta moorei*	*Bacillus thuringiensis*	*Cnaphalocrocis medinalis*, *Eutectona machaeralis*, *Helicoverpa armigera*, *Earias species*, *Plutella xylostella*, *Spodoptera litura*, *Achaeae janata*, *Hyblaea pured*, *Heliothis armigera*
Cytoplasmic polyhedrosis virus (CPV)	*Helicoverpa armigera*	*Agrobacterium adiobacter*	Crown galls
Nuclear polyhedrosis virus (NPV)	*Amsacta albistrig*, *Dasychira mendosa*, *Spodoptera litura*, *Helicoverpa armigera*, *Antheraea mylitta*,*Corcyra cephalonica*, *Spodoptera mauritia*, *Spilosoma obliqua*, *Plusia peponis*, *Pseudaletia separate*, *Plusia chalcites*, and *Pericallia ricini*	*Bacillus subtilis*	Bacterial leaf blight (paddy), Sigatoka (banana)
Granulosis virus	*Phthorimaea operculella*, *Cnaphalocrocis medinalis*, *Pericallia ricini*, *Chilo infuscatellus*, and *Achaea Janata*	*Pseudomonas cepacia*	Pathogenic fungi of soil
		Bacillus pumilus	Powdery mildews, rust, and downy
		Bacillus moritai	Diptera
		Pseudomonas chlororaphis	Fungal pathogen of barley and oats
		Pseudomonas fluorescens	Meloidogyne species

Table 6: Pathogenic fungi for insect crop pests.

Fungus	Target pest	Crop	Author (s)
Beauveria bassiana PDRL1187,	*Lipaphis erysimi*, Mustard ahpid, *Aphis craccivora* Koch	Canola (*Brassica napus* L.)	Ujjan and Shahzad [88]
Beauveria bassiana BB-01	*Schizaphis graminum*, *Lipaphis erysimi*, *Rhopalosiphum padi*, *and Brevicoryne brassicae*	Laboratory	Akmal et al. [89]
Beauvaria bassiana	Whiteflies	Melon	Palumbo [90]
Beauvaria bassiana	Myzus percsicae	Cabbage	Michereff Filho [91]
Verticillium lecanii V17, PDRL922	Mustard aphid (*Lipaphis erysimi*, *Myzus persicae*), Cabbage aphid	Cabbage, Canola (*Brassica napus* L.)	Ujjan and Shahzad [88], Asi et al. [92]
Verticillium lecanii	*Myzus persicae*, *Aphis craccivora Koch*	Chili	
Paecilomyces fumosoroseus n32,	Mustard aphids, *Plutella xylostella*, Diamondback moth, *Lipaphis erysimi*,	Cabbage, Canola (*Brassica napus* L.)	Ujjan and Shahzad [88], Asi et al. [92], Hsia et al. [93]
Metarhizium anisopliae	*Aphis craccivora Koch*, Mustard aphids, *Lipaphis erysimi*, *Aphis gossypii*, Cabbage aphid,	Canola (*Brassica napus* L.), Cabbage	Ujjan and Shahzad [88], Asi et al. [92]
Peacilomyces lilcinus PDRL812	*Lipaphis erysimi*, Mustard aphids,	Canola (*Brassica napus* L.)	Ujjan and Shahzad [88]
Hirsutella thompsonii	*Aphis craccivora Koch*	Cowpea	Saranya et al. [94]
Cladossporium oxysporum	*Aphis craccivora Koch*	Cowpea	Saranya et al. [94]

4.6.4. Nematodes. Entomopathogenic nematodes (EPNs) are soil worms that feed on insects and have a significant potential for biocontrol in crops (Table 7). The most common EPN species used in insecticidal formulations are*Heterorhabditis bacteriophora*, *Steinernema scapterisci* (mole cricket nematode), *Symbiobacterium thermophilum*, *Steinernema carpocapsae*, *Steinernema feltiae*, *Heterorhabditis megidis*, and *Steinernema riobravis*. EPN-infected juveniles (IJs) enter through natural openings such as the intersegmental membrane, anus, spiracles, or mouth and actively search for their hosts in the soil. Once within the body of the host, the EPNs release symbiotic bacteria into the hemocoel, leading to bacterial septicemia and the host's death (the infectious phase). Then, during nematode reproduction, the insect carcass and symbiotic bacteria are utilized as a food source (necrotrophic phase). In response to a food shortage, an infectious L3 nematode larval stage re-establishes contact

Table 7: List of some important nematode species and their target organisms [97].

S. no.	Nematode species	Host
1.	*Steinernema riobrave*	Citrus root weevils (Diaprepes species) mole crickets
2.	*Heterorhabditis marelatus*	White grubs (scarabs), cutworms, and black vine weevil
3.	*Heterorhabditis megidis*	Weevils
4.	*Steinernema scapterisci*	Mole crickets (*Scapteriscus*)
5.	*Steinernema feltiae*	Fungus gnats (*Bradysia*), western flower thrips, and shore flies
6.	*Steinernema glaseri*	Scarab beetle, white grubs (Japanese beetle, Popillia species), and banana root borer,
7.	*Heterorhabditisbacteriophora*	Black vine weevils, cutworms, corn rootworms, white grubs (scarabs), flea beetles, and citrus root weevils (Diaprepes species)
8.	*Heterorhabditis indica*	Fungus gnats, root mealy bugs, and grubs
9.	*Steinernema kraussei*	Black vine weevil (*Otiorhynchus sulcatus*)
10.	*Heterorhabditis zealandica*	Scarab grubs
11.	*Steinernema carpocapsae*	Billbugs, sod webworms, banana moths, dogwood borer orchard pests, armyworms, chinch bugs, cutworms, crane flies, ornamental and codling moths, cranberry girdler peach tree borer, and other clearwing borer species, black vine weevil and shore flies (*Scatella* species)

with the bacterial symbiont, resulting in IJs that emerge, depart the corpse, and go in search of a new insect (free phase). Steinernema species carry the bacteria *Xenorhabdus* spp., whereas Heterorhabditis species carry the bacteria *Photorhabdus* spp. [95]. Nematodes must be in a wet environment to remain active. Wood-boring larvae that maintain their tunnels open are good candidates for EPNs, which thrive in dark and moist conditions [96].

4.7. Chemical Control. The most effective pesticides for IPM are those that have little to no effect on the behavior of natural enemies while providing maximum control of the target insect [98]. Pesticides are any compound or combination of substances that are known to eliminate, repel, or mitigate any pest. Pesticides, including insecticides, acaricides, fungicides, and herbicides, are crucial crop management tools and have a big impact on global agricultural production [98]. Additionally, they are separated into four categories based on their intended use: plant growth regulators, defoliants, fumigants, and desiccants. Chemical pesticides are grouped into several groups based on their mechanisms of action, and switching between chemicals from different modes of action groups is advised to reduce the risk of the formation of resistance [99]. They may be obtained and derived from living things (such as allelochemicals, botanicals, insect growth regulators, and pheromones) or from man-made (synthetic) substances that are obtained from other natural sources (inorganics) [33]. However, chemical control is commonly abused, particularly in crops that are grown on a large scale, like soybeans [100]. Not just insecticides or acaricides but also fungicides, foliar nutrients, plant growth regulators, herbicides and chemicals that might be sprayed on canopies should be considered while highlighting the significance of selective pesticides in agriculture [101].

4.8. IoT in Pest Control. Despite the best attempts to prevent them, pests remain a problem for farmers. Beyond conventional farming methods, technology, particularly the IoT, may hold the key to an answer. IoT can link sensors and out-of-the-box equipment that automates, visualizes, and analyzes data to guide prompt action [102]. IoT should be considered in the field of pest management, which is not typically done. Here are a few instances of how it can be used.

4.8.1. Monitoring for Pests. Use remote surveillance to look for specific pests and learn about their behavior, habitats, and patterns. This is possible by automating monitoring and data collection, tying traps together to report specific pest levels, and implementing more accurate and prompt countermeasures [103]. One illustration would be an apple orchard that wanted to monitor the amounts of codling moths in various parts of the property so it could be prepared to act when required [104].

4.8.2. Weather Monitoring. Monitoring extremely local weather patterns can also provide further information for estimating the amount and level of harm posed by pest populations [105]. As an illustration, consider olive plantations attempting to control fruit flies and larvae, which cause the fruit to fall off the trees too soon. When monitored in real-time, temperature and precipitation are important predictors of fruit fly activity and can help determine the appropriate course of action.

4.8.3. Chemical Automation. Farmers can apply less pesticide and get better results by keeping track of the amounts on plants over time. A farmer may need to use pesticides more frequently if it rains, but depending on how a storm affects different parts of the crop, pesticides may be used excessively or insufficiently in some places [106]. Typically, sensors in the soil or above ground, close to plants, can be used to measure chemical levels [107].

4.8.4. Health Monitoring of Crops. To help you spot potential pest problems and catch them early can be compared projected crop growth to actual crop growth while taking weather and other factors into mind [108].

4.8.5. IPM Automation. The IPM process becomes more precise, timelier, and less onerous for the farmer by automating time-consuming IPM tasks like monitoring different data points on a farm and responding to that data [109].

Integrating the aforementioned IoT capabilities into a comprehensive solution makes an accurate understanding and response possible. To help guide action during this crop cycle and in the future, it is possible to trace the full history of the pest's attack on the crop, the quantity of pesticide used, and how much the yield of crops is impacted.

4.9. Drones in Pest Control. Drones allow for the treatment of very specialized areas, such as weed patches or disease sources. Drones can offer sensible, effective, and green alternatives to foliar treatment for the control of pests and diseases [110]. They, also known as unmanned aerial vehicles (UAVs), have become increasingly ubiquitous due to their capacity to operate fast and their wide range of potential uses in a number of real-world scenarios. The scientific community has recently given agricultural precision using UAVs a great deal of consideration. Multiple methods, for instance, face challenges like how to investigate the area in the least amount of time while avoiding having additional drones examine the same area, find parasites, and limit their spread by using an adequate amount of pesticides [110].

Two of humanity's most basic needs, fiber and food, are met through agriculture, a significant source of wealth for many nations. Due to technical advancements like the environmental movement, agriculture has seen a substantial transformation in recent decades. Managing livestock, commodities, and water depth are only a few of the issues that are the focus of agricultural research. Thanks to a variety of sensors and equipment on deck, the drones can complete these tasks [111].

UAV usage is The Insect Pest Administration is a one-of-a-kind collection that displays the latest innovations for the study and advancement of drones that operate independently. Such innovations include the detection and delineation of invasions of insect damage and pest habitats, as well as the supply of microorganisms and technology to soothe pest-related anxieties. Satellite imagery technology, such as spacecraft and UAVs, is employed to identify the presence of insect predators on fields and rapidly alert farmers to the issue. The advantages of heavy-altitude imaging for agriculture, which is based on satellites, comprise an expansive monitoring region, precise adaptability, a relatively brief return period, and a modest expenditure. For a variety of catastrophe monitoring purposes, a space-based system is beneficial since it can cover a vast agricultural area. It is harder to meet this requirement for pests and pest monitoring in agricultural regions since satellite monitoring is heatwave-sensitive and has inferior precision [112].

A consistent and digital approach to agricultural insect and disease surveillance is required wherever drones are used to detect the presence of pests and insects. Those features currently have an impact on the advancement and application of drones in modern farming [113].

We believe that the multidisciplinary approach is the best method for carrying out advances in research and transmission, which leads to a quicker rate of development and application of these innovations to improve pesticides. These approaches were unquestionably not associated with entomology when they were developed [114]. Drones use an autonomous technique to look for insects that are message-driven. A device to store data is included inside every UAV and is used to save encrypted copies of previously inspected destinations. The drone updates its geographical location with every flight by adding new details and erasing erroneous information. The UAV may employ such mapping to help it decide what to do next [115]. To avoid going to the same place more than once and to synchronize UAV activities, the drones occasionally broadcast signals over the earlier-occupied area. This speeds up insect extermination and research efforts [116].

5. Knowledge and Adaptation Status of IPM

Since IPM may effectively utilize both contemporary technology and conventional agricultural systems based on indigenous farming methods, it is projected to remain a dominant theme in the near future. IPM considers every economic, environmental, and social factor, which also ensures that consumers have access to healthy food [117]. Excessive application of chemical insecticides by farmers caused rapid resistance development in targeted insect pests and also had harmful impacts on the human body and nontarget species. The usage of pesticides can be significantly reduced in farming systems based on IPM technology without negatively affecting yield [118]. To make proper decisions, farmers need to have adequate knowledge about various ancillary aspects of IPM, like different control methods, the biology of pests, potential pest damages, the suitable application of available resources, etc. [3].

Most of the studies showed that male farmers' IPM knowledge is generally higher than that of female farmers. The educational level of farmers has a positive correlation with their knowledge of IPM [119]. But the age of the farmer is negatively correlated with it. Providing agricultural knowledge and technology, including IPM, to farmers in a timely and effective manner is a challenge for agricultural extension agents. As a result, farmers had a limited understanding of the fundamental principles guiding alternative pest management techniques [120]. One study showed that only a very limited percentage of farmers had received IPM training (Figure 2) [121]. Therefore, farmers must be knowledgeable about all related fields of IPM, such as biological, cultural, physical, and other techniques of pest management. Due to a lack of proper knowledge about IMP in vegetable production, farmers are less interested in adopting IPM or other nonchemical pest management techniques. As a result, the farmers' knowledge of IPM had a positive impact on its adoption, which suggests that IPM adoption could increase with adequate education and training [122].

IPM knowledge is higher among people who have engaged in more IPM-related activities than among those who have not [123], and their adaptation rate to IPM is high. Vegetable farmers' adoption rate of IPM was only 30%. Farmers got almost the same yield even though they used pesticides (glyphosate, acephate, deet, propoxur, metaldehyde, boric acid, diazinon, etc.) [118]. Their overall

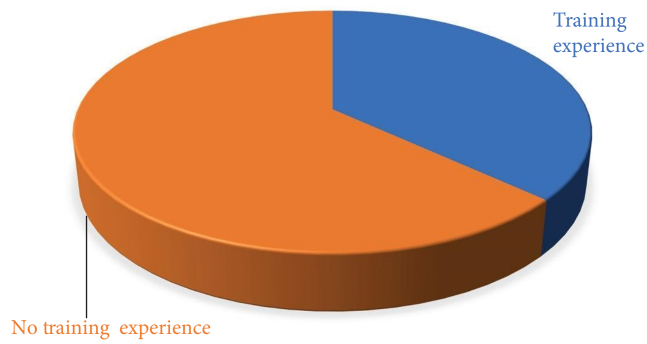

Figure 2: Percentage of IPM training received and non-received by farmers [121].

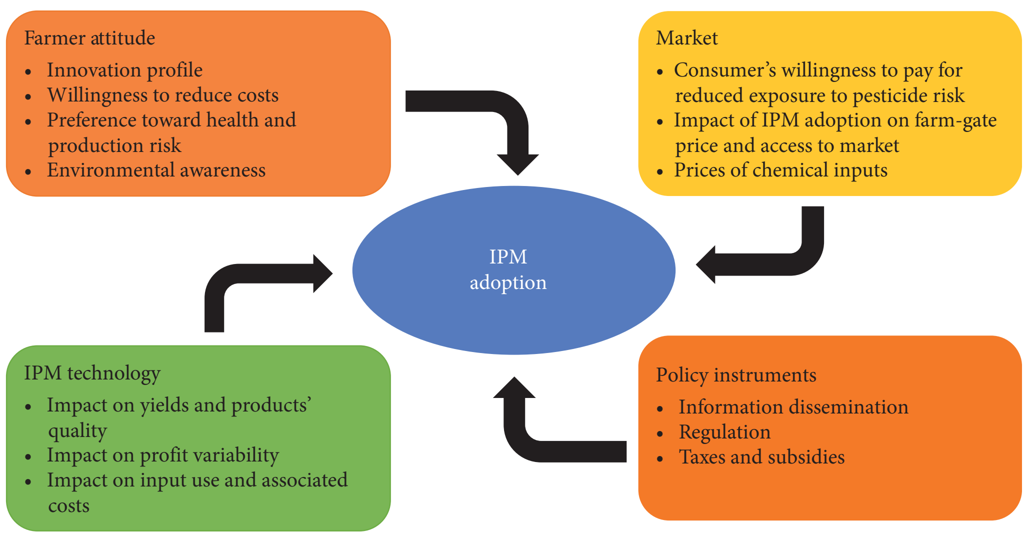

Figure 3: Framework of IPM adoption.

frequency of pesticide treatment decreased as a result, which helped them lower their input costs. The adoption of IPM concepts can benefit farmers economically by lowering costs [124]. Proposed a framework with four main categories related to IPM adoption (Figure 3).

There are four additional general management components, such as weed management, insect-pest management, general management, and ecosystem management [125]. Instead of implementing all IPM techniques at once, farmers in a specific region may implement broader IPM methods based on common management focuses [125]. Numerous factors, such as farmer land ownership status, farmers' attitudes toward IPM, field school, extension contact, and use of enhanced varieties, became more significant and had a positive impact, which increased the probability of IPM adoption [118]. Above all, farmers' extensive knowledge of IPM is a prerequisite for its widespread adoption.

6. Resources and Tools of the IPM

To get the most benefit from the advantages of an IPM approach, proper use of IPM tools and technology is recommended. Too frequently, a lot of IPM tools and technologies are not implemented appropriately because of practical issues, including high commercialization costs or a lack of interest in their adoption [3]. Some methods that have always worked to get rid of pests are trapping because of delimitation, using biopesticides and insecticides (density-dependent strategies), preventing mating (density-independent suppression technologies), and the sterile insect technique (SIT). It seems like it would be a good idea to use a technology that works quickly, like a combination of biopesticides and the release of sterile insects, or other methods that depend on population density and work against the target population [126].

The likelihood of successful eradication would rise if there were a wider range of tools and technologies available for the suppression and delimitation of pests; however, this is not the case for all insect taxa. Social approval is required in urban areas for eradication by new tools and other activities [127]. A single tactic targets various life stages, which will decimate a population more quickly while limiting the propagation and consequently the infested region. This improves productivity, reduces costs, and permits the introduction of more surveillance traps, raising the possibility of the disappearance of pests, which indicates a successful eradication. In the future, quantitative eradication program analysis will be useful to establish the likelihood of success and major variables influencing the outcome in the eradication of arthropods and other relative pests [128].

General tools used in different methods of IPM:

(1) Tools of the Physical Method: Hand picking net (O, V, etc shaped), temperature modifier/regulator, ultraviolet (UV) and infrared radiation (IR) light sources, flame thrower, light trap, sound sources, electric flash gun, etc.
(2) Tools of the Mechanical Method:
    (a) Mechanical barrier: Sticky tape in trees, fences, trenches for crawling- insects, etc.
    (b) Mechanical trap: Pheromone trap, wing trap, heliothis trap, water pan trap, PHerocon II trap, sticky trap, methyl eugenol trap, delta trap, funnel trap, sucking trap, pitfall trap, etc.
(3) Tools of Biological Method: Natural enemies, predators, parasitoids and microbial pathogens are mostly used.
(4) Tools of Behavioral Method:
    (a) Pheromones: Different types of pheromones such as sex pheromones, trail pheromones, aggregation pheromones, alarm pheromones, etc.
    (b) Allelochemicals: Allomones and kairomones
(5) Tools of Biotechnological Method:
    (a) Hybridization technology
    (b) Soma clonal variability
    (c) Transgenic plants (here, plants are treated by the addition of the following genes: lectinenzyme, amylase inhibitors, protease inhibitors, and *Bt* endotoxin from *Bacillus thuringiensis*
    (d) Male sterile technique
(6) Tools of the legal method: Quarantine management.
(7) Tools of chemical method: All selective chemicals.

6.1. Novel Tools and Technology

(i) For the control of insect pests, new methods are now being developed. Unfortunately, many of them cannot be used broadly. The most useful tools will probably provide generic solutions that can be easily customized for various targets. The ideas listed below are intriguing and could eventually result in new tools.
(ii) To provide future programs with more possibilities, new genetic techniques are being developed, such as genetically modified sterile insects with a dominant, repressible, lethal genetic system. Recently, field releases have also been conducted [129].
(iii) Arthropod pest population growth can be controlled genetically by using techniques like the release of insects carrying a dominant lethal and SIT [130].
(iv) Genetics and biotechnology have made it possible to use new, highly effective, and not-too-expensive ways to control genetics. One example is the use of clustered, regularly interspaced short palindromic repeats technology in some of the main disease vectors [131].
(v) The microencapsulated moth sex pheromone was applied to sterile Mediterranean fruit flies (mass-reared) before they were dispersed in the urban area, successfully disrupting the moth mate location. This strategy has been designed to resolve the concern of general people regarding the aerial application of pheromones, but it would necessitate the routine release of those treated flies and other effective application techniques [127].
(vi) The potential application of nonvirulent, insect-specific viruses to stop the transmission of insect-spread diseases [132].
(vii) Under the concept of cross-species behavioral disruption, insects are utilized as weapons against other species. Even though para-pheromones were successful in getting male fruit flies of one species to attract and physically interact with another species during the day, experiments to stop fruit flies from mating at dusk were not successful.
(viii) *Stichotrema dallatorreanum* (Strepsipteran parasite) appears to show potential as a new bio-control agent for the management of the pest Tettigoniidae.
(ix) Fluid jet polishing and multijet polishing are proving to be effective techniques for improving polishing effectiveness. This particular method is applicable for polishing the surfaces of boards. Additionally, by cleaning many lens units at once, it can be used to provide very effective surface polishing for large-scale lens arrays [133].
(x) Antiaggregation chemicals were used to prevent the Scolytidae from responding to their aggregation pheromones while protecting vital hosts, causing the pest to scatter, which may work against the intention of controlling an outbreak [134].
(xi) A variety of underlying genetic and cytoplasmic factors can result in sterility in hybrids produced by crosses between closely related species.
(xii) Eradication programs will continue to benefit from the advancement of current technology and its knowledge-based integration, along with the continuous development of innovative techniques. The success rate of invasion responses should rise with the combination of various strategies that have significant synergy or in a sequential use pattern [126].
(xiii) In the future, conditional lethality may be used to create sterile males without using of radiation, such as "Release of Insects with a Dominant Lethal" in the medfly system, which maintains a medfly culture dependent on antibiotics. In culture, larvae

treated with antibiotics can survive, but their crossed offspring die due to lack of antibiotics [135].

(xiv) Initially, fluorescent protein markers were used in transgene use in SIT, and these markers have recently become available for the pink bollworm [136].

7. Limitations of IPM

IPM is reinterpreted for current times when improved agricultural techniques and methods of communication play a crucial role in food consumption and manufacturing. Agriculture is an aspect of global commerce that is influenced by various other variables, and IPM is a feature of agriculture, which is a business focused on serving consumers [3].

Small-scale urban farmers are much more widely mentioned as lacking fundamental horticultural expertise than their rural counterparts, possibly because they are more likely to have nonfarming experiences [137] and can be adversely affected in many other ways (e.g., via linguistic limitations). Unprofitable companies frequently offer these farmers fundamental agricultural instruction, perhaps in collaboration with urban planning agencies as well as other vendors of services. Despite the fact that controlling weeds and pests is frequently quoted as one of the major difficulties confronted by these farmers, agricultural instruction typically gives a basic understanding of pest control [138]. Limited internet connections or unfamiliarity with online sources of information may be obstacles, especially in remote locations where internet access may not be available and also in affluent nations [139]. Perhaps a more significant issue than the availability of advisory services is the paucity of IPM research pertinent to subsistence agriculture [140]. Local farmers may not be able to employ specific pest control strategies due to cost alone, besides the fact that particular inputs may not be available in packing quantities that are acceptable for their range [141]. The one and only package quantities that the pheromone transmitters now come in are considered too large to meet the demands of farmers with large plantations. Another issue is that when dealing with vendors of farming equipment, local farmers may require more negotiating skills [140].

Mechanical and physical management strategies are the most primitive approaches used to directly combat pests. They either destroy the pest, restrict its usual path of attack, or change the atmosphere to deter pest behavior. Concerns regarding the actual harmful effects of pesticides on human beings and the ecosystem have grown as a result of the extensive use of these incredibly poisonous pesticides, especially in agricultural activities. The categorization of pests has undergone a significant change both historically and geographically as a result of changes in farming practices, biodiversity, and ecology. There are often outbreaks as a result of several pests expanding their cosmopolitan distribution and developing pesticide resilience [142]. From a technological and theoretical standpoint, each of the physical, chemical, biological, and cultural methods has limitations that affect how well they work to manage a particular pest. Prior to ultimately choosing the best strategies to use, several other considerations are considered, including the benefits and drawbacks of each method. Strict regulations limit the range of alternatives even though we proceed from manufacturing to consumption. Considering postharvest circumstances, a variety of physical methods of control are employed. The mechanisms of operation for chemical techniques are clearly specified and constrained. Modernization of the infrastructure is often linked to reasonable expenses. Adjusting the standards' criteria for good sanitary and hygienic practices to specific limits is another hurdle to the deployment of IPM [65].

Bacterial agents are now being used more often in IPM methods due to current issues with the use of conventional pesticides and the focus on sustainable farming with minimal costs [143]. EPF require specific climatic conditions to spread and multiply diseases. EPF have a short lifespan and are extremely expensive to manufacture for commercial applications [48].

8. Future Needs

Suitable solutions are urgently required due to the widespread concerns about relying on chemical pesticides, which are well established. To make sure that the insects do not pose a hazard to the plant, the physical habitat of the pest is changed using physical procedures. Stress levels ranging from aggravation to death can be produced in order to achieve this. This can also be accomplished by employing tools like structural obstacles that prevent pests from getting into crops. By increasing IPM treatments, there is now a widespread desire to reduce pest infestations at all points in the pre- and post-harvest food production processes. We feel that physical methods of control would be more widely employed if management fully understood the "real worth" part of IPM deployment as contrasted to the easier traditional pest management techniques. The employment of skilled individuals with in-depth expertise in the expansion of humans and the activity of the main agricultural pests is necessary for the use of physical manipulation techniques. In order to make it easier to incorporate individual elements, commencing an IPM program sometimes necessitates improving the structure's layout and modifying the component design [65]. The impact on microorganisms that are not targeted is negligible. Precision farming would undoubtedly benefit from the majority of diseases' ability to replicate themselves both spatially and temporally [143]. For the comprehensive and typically risk-free management of insect pests in agricultural production, mycoinsecticides have the capability to serve as a key element of an IPM program. The effectiveness of the goods in adverse climate factors, compositions that would improve permanence, have a longer lifespan and are easy to use, as well as pathogenic aggressiveness and range of effect, all require emerging interdisciplinary efforts to accomplish this. The sustainability of pest distribution and abundance in ecological systems is greatly influenced by the actions of EPF. An awareness of this function led to the investigation into the potential use of infectious fungus in the control of insect pests [48]. It has been established that biological treatment is an option that is beneficial for the environment. While teaching farmers how to utilize cultural approaches properly and how to incorporate them into other tactics ought to be a focus of biochemical management. In addition, it is crucial to examine the various microbiological product preparations that will produce the most effective outcomes. From the manufacturer to the customer, every link in the product lifecycle must try to promote and embrace biological control measures. To increase consumer awareness of biostimulants, promotional initiatives, including exhibitions, advertisements, and apprenticeship programs, can be carried out. For use in many environments and temperatures in the future, the search for innovative microbial inoculants should continue. Considering greater effectiveness, usability, and expenditure, improved manufacturing, conceptualization, preservation, and surface treatments must be developed. For important agricultural plants, microbiological genomes can be inserted into conventional breeding. To understand the epidemiology of insect diseases and ensure their long-term usage, a considerable study is required.

9. Conclusion

Diseases, weeds, and pests that affect crops represent a serious threat to agricultural livelihoods, food security, and efforts to reduce poverty. There are numerous ways to minimize harm with IPM strategies. IPM is reformulated for contemporary times, where sophisticated agricultural technologies play a crucial role in food production and consumption. IPM is far more than an ordinary resource-saving technique. IPM techniques require a lot of knowledge, much as other sustainable intensification methods do [1]. In this review, we highlight the present status and development of IPM. Advances in technology have now ushered in a new chapter in IPM. After all, there are some limitations to this process. We have identified those limitations and set some future works in this review. Extension officers needed to increase the training on IPM. This will help farmers to understand pest management as well as they can increase their crop production. Government assistance is necessary for this. If IoT is used in conjunction with the current pest management technique, IPM will also achieve a new milestone. IPM advice is needed to support sustainable farming techniques that combine profits for crop farmers, affordability for consumers, food security, and environmental conservation for the expanding global population.

Data Availability

This manuscript is a review, based on the published articles that are referred and listed in the reference lists of the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

P.B.A. developed the idea and designed the structure. S.M., I.J., M.D., U.B.A., F.J.A. and P.B.A. collected the data. P.B.A., S.M., I.J., M.D., U.B.A., F.J.A. and M.S.I. wrote the manuscript and prepared the final version of the manuscript. P.B. A. revised the manuscript.

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