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Review Article

Comparing Traditional and Contemporary Approaches to Integrated Pest Management in Major Field Crops

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Abstract | Conventional methods of insect control have faced significant challenges, primarily due to the extensive use of pesticides. This overreliance on pesticides has led to issues such as pest resistance and environmental pollution. Some formerly minor pests have transformed into major threats by altering their biology and host preferences. Integrated Pest Management (IPM) offers a promising solution by reducing the reliance on insecticides. Many countries worldwide have successfully adopted IPM techniques to manage crop pests. However, in countries like Pakistan, the adoption of IPM practices remains limited among farmers, resulting in a lack of significant success stories in this regard. In light of the challenges posed by pest adaptation and pesticide resistance in the context of climate change, it becomes imperative to consider IPM as a viable solution. Farmers aiming to implement successful IPM programs should prioritize understanding pests, crops, and the environment. Rather than seeking complete pest eradication, the primary objective should be to manage pest populations at acceptable levels. This review article underscores the significance of (IPM) integrated pest management for farmers as an economically and ecologically sound methodology of pest control. It emphasizes the importance of a comprehensive understanding of pest dynamics, crop behavior, and environmental factors in achieving effective pest management in an evolving climate.

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Introduction

Integrated Pest Management (IPM) is an approach to control pests by using acceptable practices that are economically sound and environmentally safe. It creates collaborations by integrating preventive methods drawing from a diverse array of approaches. It is important to bring pest populations into suitable level rather than eliminating them. A successful IPM program hinges on a profound understanding of the interplay between pests, crops, and the environment. IPM is a strategic approach that relies on economically viable and environmentally safe practices to achieve this balance (Abbas *et al*., 2022). IPM had defined in different ways in the past. Like "It entails pest management rather than mere pest control and encompasses a multifaceted approach, encompassing factors like plant nutrition, physiology, resistance, and economic considerations" (Colmenarez *et al*., 2016). The U.S. Department of Agriculture originally defined Integrated Pest Management (IPM) as a science-based decision-making framework with a historical foundation, aimed at minimizing and pinpointing pest risks along with related policies (Stern *et al*., 1959). Subsequently, their updated definition characterizes IPM as a sustainable practice rooted in science, which employs a holistic approach encompassing cultural, physical, biological, and chemical tools to identify and manage pests, thereby reducing risks not only to the economy but also to health and the environment. This comprehensive strategy contributes to an overall decrease in economic, health, and environmental threats posed by pests. Naranjo and Ellsworth (2009) laid out a comprehensive framework IPM, delineating four crucial components. Firstly, it emphasizes the significance of establishing thresholds as a means to determine the necessity for implementing control measures. Secondly, it advocates for the application of sampling techniques to identify crucial pest population densities, thus facilitating informed decision-making. Thirdly, it underscores the vital importance of understanding and preserving biological control mechanisms, acknowledging their pivotal role in Integrated Pest Management (IPM) strategies. Lastly, it highlights the prudent utilization of selective insecticides as a critical component within the broader array of pest management techniques. Food and Agriculture Organization (FAO) defined as "it is pest control system associated with environment and pest, exploits all techniques and methods in such a combined way that keep pest population below economic injury levels (EIL) (FAO, 2011). Steps for a successful IPM program are proper identification of pest and their damage, biology of pest and host, monitoring, establishment of threshold, appropriate combinations of management tactics and evaluation of results. However, an Integrated Pest Management (IPM) program demands a substantial level of management oversight, labor-intensive efforts, and its success can be contingent upon weather conditions. (Rezaei *et al*., 2019). Recent research has revealed a deficiency in the integration of both contemporary and traditional approaches essential for the achievement of a successful Integrated Pest Management (IPM) system. The implementation of IPM hinges on a multifaceted interplay of numerous factors, including economic and social conditions, educational levels, ethical values, environmental consciousness, regulatory considerations, the accessibility of IPM tools, farmer preferences, extension education, and governmental policies. These diverse components collectively shape the landscape within which IPM strategies must operate effectively (Lefebvre *et al*., 2015).

History of integrated pest management

Over the last three decades, Integrated Pest Management (IPM) has emerged as a crucial framework for coordinating research and extension activities on a global scale. Since its inception, IPM initiatives have proliferated and are now being actively implemented across the world (Kaur and Kaur, 2020). In 4700 B.C.-Silkworm culture in China (Orlob, 1973), 2500 B.C. Use of sulphur to control insects (El-Shafie, 2018), 1500 B.C. 1st description of cultural control (Orlob, 1973), 1200 B.C.- Botanicals were developed (El-Shafie, 2018), 324 B.C. Chinese introduced ants to manage caterpillar in citrus, 13 B.C. 1st Rat proof granary was constructed in Rome, 1763- Linnaeus gained recognition for his groundbreaking essay on the use of mechanical and biological control methods for the management of orchard caterpillar infestations, which earned him prestigious awards, 1880-1st commercial pesticide machine, 1888- 1st major biological control success, 1921-1st aircraft for spray (Orlob, 1973), 1940- The concept of supervised control, 1959- The three concepts in question were the Economic Threshold Level, Economic Injury Level, and Integrated Control (Stern *et al*., 1959), 1961- Ecologists used the word 'Pest Management'(Geier and Clark, 1961), 1962- Book published "Silent Spring" (Carson, 1962), 1966- The term "Pest Management" received recognition in USA, 1967- Smith and V.D. Bosch used term "IPM" (El-Shafie, 2018), 1967- FAO panel of experts accepted the term "Integrated Pest Control" as a synonym for integrated pest management (FAO, 1968), 1970- New theory of IPM was born, 1972- A bacteria (BT) *Bacillus thuringiensis* was unconfined for the control of lepidoptrous pests (Peshin *et al*., 2009), 1977-1st registration of insect pheromone (Orlob, 1973), 1988- IPM success in Indonesia (Dhaliwal *et al*., 2004), 1989- Farmer field school for IPM, 1996-

Crops having transgenic resistance against pests were introduced (El-Shafie, 2018), 2011-60 countries were operationalized with IPM programs (FAO, 2011), 2012-FAO and United states EPA defined IPM (Ehi-Eromosele *et al*., 2013), 2014-Eight IPM principals were executed in National Action Plan (Union, 2009).

Eight Principles of Integrated Pest Management (Barzman *et al*., 2015).

Prevention and suppression: It is combination of tactics to bring into preventive strategies.

Monitoring: It is based on observation, forecast and diagnostic.

Decision making: It based on use of threshold under multiple criteria.

Non chemical methods: These may be less efficient than pesticides, cam develop valuable synergies.

Pesticide selection: Development of new valuable biological agents and products

Reduced pesticide use: It relies on partial use of pesticides to reduce human and environmental risks.

Anti Resistant Strategies: It is use of pesticides at lower dose than recommended on the label. Overdose causes sublethal and hormesis effects.

Evaluation: Assessment of entire processes of control strategies for the adoption of new standards for sustainable production.

Cultural control tactics

Cultural control encompasses a range of techniques designed to render crops less accessible, less appealing, and less palatable to a variety of crop pests. These techniques encompass practices such as land management and tillage, irrigation management, the application of fertilizers, sanitation measures, the use of resistant crop varieties, the planting of trap crops, and the careful timing of sowing and harvesting (Alston, 2011). The ultimate aim of these cultural practices is to create an environment that is conducive to crop growth while simultaneously discouraging pest infestation and development, thereby promoting crop health and reducing susceptibility to pest damage (Hill, 2008). Tillage causes desiccation, mechanical land injury which destroys different life stages of pests by exposure to the predators, sun heat etc. Periods of high pest densities van avoided or escaped by altering sowing and harvesting dates of various crops e.g., to control whitefly in cotton, sanitation, altering sowing and harvesting schedules plays a vital role regarding population suppression (Abbas *et al*., 2022). Crop rotation is a displacement of crops with one another on annually basis with is effective in destruction of soil pests with poor dispersal capabilities and limited pest mobility (Mohler and Johnson, 2009). Soybean-maize rotation has proven to be highly effective in managing a range of pests, including white grubs of beetles, pupae of various moths and flies, and notably, Lepidopterous pests like the weevil complex (Clemente *et al*., 2022). Implementing sanitation practices such as bagging fruit and adjusting the harvest schedule from two to three days significantly decreased the incidence of spotted wing drosophila infestations (Leach *et al*., 2017). Intercropping and crop rotation were successful in controlling different pests in many cropping systems (Pretty and Bharucha, 2015; Nielsen *et al*., 2016). Trap crops serve the purpose of luring pests into strategically planted areas, making it easier to manage and control them through crop destruction and the application of insecticides (Youm *et al*., 1996; Mills and Daane, 2005). Furthermore, the augmentation of both the quality and quantity of the natural enemy complex can be achieved by implementing multiple cropping schemes (Landis *et al*., 2000). Early planting dates on vast area were successfully in minimizing pest pressure in various examples. In north India damage of American bollworm was escaped by early planting of cotton crop (Dhawan and Peshin, 2009). Delaying the planting of wheat proves effective in managing Hessian fly infestations, while early harvesting of alfalfa can successfully control potato leaf hoppers and alfalfa-related issues. Likewise, to evade damage from panicle insects in sorghum, planting during the first half of May is effective (Archer *et al*., 1990). Early cessation of cotton crop helps in minimizing attack of pink bollworm (*Pectinophora gossypiella*). Destruction of weeds play vital role in reduction of carryover of mealybug (*Pseudococcidae*), CLCV and spotted bollworm (*Earias vitella*) on cotton crop (Dhawan *et al*., 2007). The elimination of crop residues is an effective method for eradicating hibernating larvae and eggs. For instance, to diminish the infestation of the red palm weevil (*Rhynchophorus ferrugineus*), it is essential to remove date palm trees that have been infested (Faleiro, 2006). Similarly, leafhopper densities increased by increasing irrigation frequencies in vineyard. In Florida, various colored mulches were employed with success in the control of thrips, aphids, and whitefly, as demonstrated in the study (Gilreath *et al*., 2005) Notably, silver mulch proved particularly effective in reducing thrips populations in tomato and pepper crops. In Uganda aphid, thrips and pod borer infestation can be reduced in cowpea by early high density (Karungi *et al*., 2000) and in Nigeria pod sucking bug (*Riptortus dentipes*), legume pod borer (*Helicoverpa armigera*) and legume flower thrips. Low potassium contents helps plants to bear some diseases and insect pest (Davis *et al*., 2018).

Mechanical or physical control strategies

Physical and mechanical controls encompass a range of techniques involving the use of tools, devices, and barriers to create an inhospitable environment for insect pests, preventing them from accessing their resources (Toyoda, 2020). This approach includes various tactics such as handpicking, the use of screens and barriers, trapping devices, and the employment of hand and bag nets. Additionally, physical methods encompass manipulation of temperature, sound, controlled atmosphere, and irradiation. For example, pruning infested parts of fruit and forest trees, along with defoliation in specific crops, can effectively reduce pest populations. The maize borer can be eradicated by chaffing sorghum or maize stalks and burning stubbles (Ehi-Eromosele *et al*., 2013). Another successful approach combines the use of Bt technology with handpicking, resulting in minimal pod damage (Abbas *et al*., 2016). Manual removal of egg masses has proven highly effective in controlling the cotton leafworm (Gamliel and Katan, 2012; Gogo *et al*., 2014; Dara, 2019). Among commonly employed techniques are light traps, pheromone traps, sticky traps, and sticky bands. Frequently, mechanical and physical control methods are employed in conjunction with other Integrated Pest Management (IPM) strategies. Pheromone and light traps serve the dual purpose of monitoring insect pest populations and suppressing larval populations by capturing adult moths (Abbas *et al*., 2019). Navi *et al*. (2018) found pheromone traps to be both economically efficient and successful. The effectiveness of light traps against *Helicoverpa* species in gram crops was evaluated by Farmanullah *et al*. (2015) while Dillon and MacKinnon (2002) successfully tested nine light traps in a 16-hectare area, reporting their effectiveness in reducing *Helicoverpa* egg laying by suppressing adult populations. Many researchers have utilized light traps to determine the active periods of crop pests (Ahmad, 2003; Hossain, 2008). Yellow sticky traps have long been a staple for capturing samples of both beneficial and harmful insects in cultivated and wild plants worldwide. These traps are particularly attractive to flies and fruit flies, as demonstrated by Gorska-Drabik *et al*. (2011), leafhopper (Shi *et al*., 2020), aphids, whiteflies (Atakan and Ozgur, 2001), and thrips (Pearsall, 2002). Furthermore, sticky grease bands have found wide usage in England to protect apple, plum, pear, and cherry trees from wingless moths and other pests. Percival (2016) used barrier glue bands by trunk application to control chestnut leafminer severity. In Pakistan grease bands are successfully being used to control mealy bug in mango and guava trees.

Biological control tactics

Biological control is a strategy to use other species to control pests. It is based on natural processes such as predation, parasitism, herbivory and others, but it needs active human intervention (Flint *et al*., 1998). Biological control faces a challenge in creating an economically and socially sound development method due to lack of biological data and information. The first mention of an insect species being used to control an insect pest comes from Nanfang Caomu Zhuang who said that "People in Jiaozhi sell ants and their nests attached with wings look like thin cotton envelopes with reddish yellow ants that are larger than normal. Without such ants, southern citrus fruit would be seriously insect damaged" (Shijiang, 1983). Predatory mites (*Tyroglyphus phylloxera*) were the first insect to be shipped globally as biological control agent to combat against grapevine phylloxera (*Daktulosphira vitifoliae*) in France. The first paraistoidal wasp to be introduced into United States was a braconid (*Cotesia glomerata*) from Europe in 1883-84 to control white butterfly populations (*Pieris rapae*). To monitor the cottony cushion scale, vedalia beetle (*Rodolia cardinalis*) was introduced from Australia to California in 1888-89 (*Icerya purchase*). At the end of 1889 the pest population was declined significantly (Hoddle, 2003). The 1st classical biological control was made in Canada by use of parasitoid wasp (*Trichogramma minitum*) to manage invasive pest currantworm (*Nematus ribesii*). Up to 1908 other parasitoids were also released in Canada. USA started a massive biological control program in 1905 to find natural enemies of gypsy and brown tail moths. As a response nine parasitoids species gypsy moth and brown tail moth got established in USA (Coulson *et al*., 2000). Levuana moth (*Levuana iridescences*) population was an invasive pest of coconut in Fiji and controlled working under a biological classical program in 1920 reported by (Kuris, 2003). In Australia, to control

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prickly pear cacti, scale insect (*Dactylopius*) and cactus moth (*Cactoblastis cactorum*) were introduced. By 1932 most of the plants were destroyed by these insects. In recent times biological control still effective and used in different ways. Trichogramma eggs are being used to control a number of moth species. In Europe, *T. evenescen*, *T. brassicae*, *T. cacoeciae*, *T. dendrolimi* are marketed to manage lepidopterous pests in greenhouse and *Ostrinia nubilalis* in corn and orchards. *Encarsia formosa* and other natural enemies are also used in greenhouses. Predatory stink bug (*Euthyrhynchus floridanus*) considered in Florida to control bugs, beetles and caterpillars (Anthony, 2013). Entomopathogenic nematods are used to control variety of pest on agricultural crops (Mracek *et al*., 1993) e.g., Yan *et al*. (2013) controlled soil larvae by using *Heterorhabditis indica* and *Steinernema carpocapsae* effectively. Fungus is also a successful control agent used against different pests such as *Spodoptera* species (Purwar and Sachan, 2005). Commercial bacterium (*Bacillus thuringensis*) insecticide also successfully used against insect pest (Bravo *et al*., 2011). Coccinellid beetle, *Cryptolaemus montrouzieria* used on several crops suppress various species of mealybug. Parasitoid, *Leptomastix dactylopii* has established permanently in India on *Planococcus citri* (Singh, 2004).

Chemical control

Insecticides have played a major role in food security and will continue to do so. Insecticides should be used when absolutely necessary to avoid insect pest population below economic threshold level. Selective insecticides have the least amount of environmental damage. In the application process, it is crucial to prioritize the use of botanical and microbial pesticides. The synergistic use of these bio-rational pesticides can significantly enhance their effectiveness (Barzman *et al*., 2015). Pesticides must be applied specifically with correct doses to avoid insecticides resistance. The major objective of IPM strategy is use of pesticides in precise way to delay pesticide resistance to save biological fauna and natural environment (Dhawan, 2001).

IPM prospective and approaches in Pakistan

In 1971 Integrated Pest Management was initiated in Pakistan at PARC research station Rawalpindi, Pakistan comprising seven-years project on bollworms funded by PL-480 and three year project on whitefly funded by PL-480 (GOP, 2017). Various institutes i.e., Department of Plant Protection, Pakistan Agricultural Council and departments of entomology in universities and Ayub Agricultural Research Institute have carried out number of projects on IPM. Most of these efforts concentrated on single pest problem. Use of *Tricogramma* as egg parasite of sugarcane borers and application of pheromone methyl eugenol to control fruit flies are very common IPM techniques in Pakistan. A world bank funded project of cost 57 million was launched as a IPM component. Pakistan Agricultural Research Council has launched various projects on IPM. A 112 million project during 1993-98 and National Integrated Pest Management Projects by NARC during 2001- 02, 2001- 11 and 2011- 15 in partnership with provincial and district governments of all provinces i.e., Punjab, Sindh, Baluchistan and NWFP. Project on rearing of natural enemies has launched by Sindh government during 2019-21 (GOP, 2019). National Intitute of Agriculture and Biology (NIAB) successfully rearing and releasing Trichogramma, Chrysoperla and Bracon. Government of Khyber Pakhtunkhwa (KPK) successfully launched project on Integrated Pest Management Framework of various crops (Jabbar and Mallick, 1994; GOP, 2019). Entomological Research Institute, Faisalabad launched a project to control fruit flies of citrus, guava and mango from 2014-18 and got significant results. Many other scientists have conducted various experiments on IPM of various crop pests. Comprehensive studies of *American bollworm* parasitism on chickpea crop by *Campolites chlorideae* have been made. Infestation and population level studies of American bollworm were made by using light traps in gram (Farmanullah *et al*., 2015). Abbas *et al*. (2019) used light traps to control gram and mungbean pests. Total 32415 insect pests were captured with 30 different species. Pheromone traps successfully used to control Spotted, Pink and American bollworm. Later on pheromone traps reported as a useful tool to monitor and control Lepidopterous insect pests. *A. indica* has been shown to effectively manage populations of *Bacterocera cucurbitae* and *Bacterocera dorsalis*, as demonstrated in studies (Mahfuza *et al*., 2007; Masood *et al*., 2009; Ali *et al*., 2011). Additionally, *Citrullus colocynthis* exhibits notable repellent properties, with an overall 34.55% reduction in egg laying by *Bacterocera zonata* (Rehman *et al*., 2009). Furthermore, Ali *et al*. (2008) confirmed the larvicidal and insecticidal efficacy of *Nerum oleandera* against fruit flies. Abbas *et al*. (2015) successfully used plant extracts against *Tribolium* *castaneum* and *Oxycarenus* spp. (Ahmed *et al*., 1998; Khalique and Ahmed, 2001). Indigenous and some exotic strain of *Bacillus thuringiensis* were tested to check their bio efficacy and evaluated for commercial use (Anonymous, 1989).

Conclusions and Recommendations

Integrated Pest Management (IPM) program should be tailored to align with the unique ecology, biology, and severity of the pest in question. Sometimes, a single component can dominate the strategy, as seen with the cultural control of fruit flies, for instance. To enhance the effectiveness of IPM programs, it's vital to introduce innovative components. This may involve the integration of new crop cultivars engineered with resistant genes or the exploration of novel biological control options capable of withstanding challenging environmental conditions. Genetic engineering holds promise in the development of transgenic biocontrol agents with broad ecological suitability. There is a need for the development of pesticides that exhibit greater specificity for the target organism, efficacy at low doses, reduced toxicity to consumers, users, and beneficial organisms, minimal impact on wildlife, shorter persistence in the environment, and a shorter shelf life within the human body. Embracing an IPM approach is crucial for sustainable pest management that not only ensures economic viability but also takes into account environmental and health concerns. Farmers should endeavor to integrate these diverse strategies into their agricultural practices to secure long-term success and food security

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Novelty Statement

It emphasizes a comprehensive understanding of pest dynamics, crop behavior, and environmental factors in achieving effective pest control.

Author's Contribution

Muneer Abbas: Conceptualized, designed and wrote manuscript.
Sohail Abbas: Identified the scope of title and reviewed literature.
Imran Faraz: Identified the areas of focus.
Niaz Hussain: Conducted comprehensive literature reviews.
Muhammad Aslam and Muhammad Irshad: Selected and summarized relevant papers.
Mudassar Khaliq and Abdul Ghaffar: Conducted comprehensive literature reviews.
Zubeda Parveen and Muhammad Nadeem: Overall Management of the article.
Sana Ullah and Malik Akhtar Iqbal: Proof-read relevant portion.

Conflict of interest

The authors have declared no conflict of interest.

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