Uttar Pradesh Journal of Zoology

Volume 45, Issue 18, Page 410-422, 2024; Article no.UPJOZ.4034
ISSN: 0256-971X (P)

A Review on Various Components as an Effective Pest Management Tool under Integrated Pest Management of Tomato (*Solanum lycopersicum L.*)

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/upjoz/2024/v45i184459

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.mbimph.com/review-history/4034

Review Article

Received: 03/07/2024
Accepted: 07/09/2024
Published: 10/09/2024

ABSTRACT

The tomato, or Solanum lycopersicum L., is an essential crop for the nutritional security of the world. However, because of pests and illnesses, farmers must use excessive amounts of chemical pesticides due to cropping patterns and climate fluctuation. Good Agriculture Practices (GAP) guidelines can be met and the overuse of pesticides can be decreased with the use of integrated pest management (IPM) techniques. Developing specialized management techniques requires an understanding of the distribution, prevalence, and factors impacting the severity of insect pests.

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Cite as: *Pathak, Bhaskar, and Munindra Kakati. 2024. "A Review on Various Components As an Effective Pest Management Tool under Integrated Pest Management of Tomato (Solanum Lycopersicum L.)". UTTAR PRADESH JOURNAL OF ZOOLOGY 45 (18):410-22. https://doi.org/10.56557/upjoz/2024/v45i184459.*

With the use of workable tactics such host plant resistance, cultural practices, biological control, and mechanical/physical control methods, integrated pest management (IPM) is starting to emerge as a sustainable approach to pest management. Nevertheless, obstacles like a lack of farmer knowledge and resources prevent IPM from being widely adopted. Crop productivity and agricultural pests are being significantly impacted by climate change and extreme weather events, especially in small-scale farms. Insect range expansion increased overwintering survival, and an increased danger of invading species and illnesses are all possible outcomes of these changes. IPM implementation in small-scale production necessitates knowledge gaps to be filled, appropriate methodologies to be identified, and scale adaptations. To create agro ecosystems and reduce damage, integrated methods, intercropping, cover crops, and legume crop rotation are crucial. Digital technology, precision agriculture, biotechnological advancements, and climate-resilient approaches present opportunities. The effectiveness of IPM depends on improved farmer education, public-private partnerships, and well-informed decision-making.

Keywords: Essential crop; nutritional security; pest management; agricultural practice; pest; GAP; L; IPM; management; integrated; crop; techniques; practices; pesticides; methods.

1. INTRODUCTION

As essential providers of micronutrients, vitamins, and minerals, vegetables play a critical role in guaranteeing nutritional security on a global scale. Of all the vegetable crops grown commercially in India, the tomato (*Solanum lycopersicum* L.), which is native to South America, accounts for a large share of the country's cultivation area and production. The tomato, widely recognized for its delicious fruits and plethora of varieties, is an essential "protective and remunerative vegetable" crop because of its outstanding nutritional and financial worth [1]. Tomato is considered unique because of its following characteristics:

1.1 Nutritional Benefits

Rich in nutrients: Vitamin C, potassium, folate, and vitamin K1 are just a few of the important vitamins and minerals that can be found in tomatoes. Additionally, they are a strong source of antioxidants like beta-carotene and lycopene, which help shield cells from harm [2].

Heart health: Eating tomatoes can reduce the chance of developing heart disease. Particularly, lycopene has been demonstrated to lower inflammation and cholesterol.

Cancer prevention: Studies have shown a correlation between tomatoes' antioxidants, particularly lycopene, and a lower risk of developing some malignancies, such as prostate cancer.

Digestive health: The high fiber content of tomatoes facilitates digestion and helps ward against constipation.

Managing diabetes: Tomato ingredients may help control blood sugar levels and lower the risk of type 2 diabetes.

1.2 Economic Importance

Agricultural value: One of the most extensively cultivated short duration vegetable and eaten crops worldwide are the tomato. Cultivating tomatoes works well with a variety of grain, oilseed, pulse, and cereal cropping systems. They are an important crop that supports the agricultural economy in many nations.

Cooking versatility: Tomatoes can be utilized in a wide range of recipes, including soups, salads, sauces, and juices. Because of their adaptability, they are a mainstay in numerous international cuisines.

Employment generation: The tomato industry offers jobs in the distribution, processing, and farming sectors. Tomatoes are extensively processed and prepared for both domestic use and exportation on a huge scale.

1.3 Environmental Impact

Sustainable farming: Tomato can be grown in both outdoor and indoor conditions. Resource conservation and environmental impact can be achieved by growing tomatoes using sustainable farming methods.

Pest management: In tomato growing, integrated pest management (IPM) techniques assist preserve beneficial insects and lessen the use for chemical pesticides [3].

Nothing in gardening is nearly as satisfying as watching a tomato plant grow from a seedling to a magnificent fruit-bearing plant. This delight, though, can rapidly give way to disappointment when the valuable plants succumb to the numerous pests that are particularly drawn to tomato plants.

1.4 Pests Especially Target Tomato Plants for a Number of Reasons

Rich nutrients: Tomatoes are rich in nutrients, which attracts a wide range of pests that feed on their leaves, stems, and fruits [4].

Favorable climate: Tomatoes grow best in warm, humid climates, which are also favorable for many pests [5].

Continuous Cultivation: Tomatoes are often grown continuously in the same fields, which causes pest populations to build up over time.

Wide range of pests: Numerous pests, including as fruit borer, hornworms, spider mites, and aphids, attack tomatoes. Their eating preferences and patterns of damage vary. Certain pests not only cause direct harm to plants but also spread diseases, which makes the plants much more vulnerable [5].

It's essential to comprehend these pests' habits and methods of control if we want to keep our garden productive and healthy. Pests that affect tomatoes can range from evident leaf strippers to unseen root assassins, and they are all dangerous to the plants' well-being and yield. These pests have the ability to contaminate the plants and stop them from growing, so our hard-earned crop will be useless.

Chemical pesticide use in agriculture that is both careless and indiscriminate has led to a number of unfavourable outcomes, including ecological imbalances, pesticide residues in food, fruits, and vegetables, fodder, soil, and water, pest resurgence, risks to human and animal health, destruction of bio-control agents, and the emergence of pest resistance. As a result, since 1985, the Indian government has embraced integrated pest management, or IPM, as the cornerstone of plant protection in the Crop Production Program as a whole [6].

The concept of Integrated Pest Management (IPM) has been developed to achieve the goal of designing an economically and ecologically sustainable agro-ecosystem. This is due to the increased pressure on the commercial agriculture system from both an ecological and economic standpoint, as well as the availability of sophisticated evaluation systems. Major scientific and extension service initiatives are currently underway in several nations to offer advice on crop security matters and reduce crop losses due to pests and diseases. In order to reduce pests to manageable levels across a wide area, Integrated Pest Management (IPM) methods include identifying potential pests and understanding their characteristics, attempting to prevent their prevalence, assessing the severity of pest-disease infestation through scouting and monitoring techniques, and managing all pests and diseases in an integrated, judicial, and need-based manner. By carefully choosing the components through appropriate evaluation, our study aimed to develop effective integrated pest management (IPM) modules used in tomato crop.

2. MATERIALS AND METHODS

The methodology used in preparing this article was the information collected from various search sites such as Google, Google Scholar, Social Science Research Network (SSRN), Academia, WorldWideScience, Springer, Semantic Scholar, Research Gate, E-Theses Online Service (EThOS), Directory of Open Access Journals (DOAJ), CORE, etc. Research articles in various national and international journals and their compilations under different headings were also gathered, as part of the methodology used. In order to adequately present the important works of several IPM professionals and agricultural scientists, the article tries to highlight their tremendous efforts and works. Integrated pest management encompasses physical, cultural, biological, regulatory, chemical, and artificial intelligence measures, depending on the demands and circumstances. We could concentrate on several integrated pest management (IPM) strategies for tomato crops in this article, which can either avoid or control insect pests.

2.1 Components Used in Integrated Pest Management (IPM) in Tomato

Fig. 1. A schematic diagram of the components of IPM used for tomato

2.2 Monitor Regularly for Early Pest Detection

Keeping a close eye on the tomato plants can aid in the early discovery and control of pests. The grower should seek out indications of damage and take quick action to resolve any problems. It is necessary to look out for symptoms of insect damage, such as yellowing, wilting, stippling, or bitten leaves. One should look for adult insects, larvae, or eggs on the undersides of leaves also. Accurate pest identification helps the farmer select the best treatment strategies and controlling a pest problem will be simpler.Prevention, avoidance and suppression are the 3 main categories under cultural control of pests which enhance crop competing ability against pests as well as create a favourable environment for pest natural enemies and less suitable conditions for pest outbreaks [7].Successful integrated pest management (IPM) strategies in the production of vegetables depend heavily on insect monitoring. To safeguard productivity and profitability, treatment options must take into account the kind of insects present. Although keeping an eye out for insect pests might take a lot of time, there are quick fixes available that can identify problems with pests before they harm the crop.

2.3 Use of Resistant Tomato Variety

To increase yields and obtain high-quality produce, high-quality vegetable seedlings must be produced. Healthy plants have the capacity to prevent hunger, lessen poverty, save the environment, and foster economic growth. Between 20% and 40% of the world's food production is lost due to pests and diseases, and each year, trade losses in agricultural products surpass USD 220 billion. Furthermore, once a plant pest becomes established in a new area, it is almost impossible to eradicate it. Climate change exacerbates this situation; its effects on plant health are irrefutable and have an impact on the epidemiology, distribution, and effects of plant pests [8].

Using clean seed is essential to preventing insect infestations from the beginning [9] Tomatoes have been developed in certain kinds to withstand common pests and diseases.There are many varieties of tomato in the market that are resistant to diseases like Fusarium Wilt. Tobacco Mosaic Virus, Verticillium Wilt, Leaf Mold, Root Knot Nematode, Fusarium Crown & Root Rot, Late Blight, Tomato Mosaic Virus, Tomato Yellow Leaf Curl Virus, Bacterial Speck, Tomato Spotted Wilt Virus, Resistant to disorders, Gray Leaf Spot etc [10]. Bush big boy, Bush early girl, Sweet tangerine, Fourth of July, Big beef are pest

resistant tomato varieties that are available all throughout the world.

2.4 Maintain Proper Sanitation

Consistently maintain good field sanitation by removing and trimming infested plant parts, ensuring the area is clear of weeds and debris, and regularly cleaning all farming tools and equipment are some of the most traditional and successful strategies used by farmers to manage pests in their crop fields [11]. Cleaning up fallen fruit and plant debris from the garden on a regular basis and disposing of away from the farm land area is very important since they may contain pests and diseases. By decreasing the development conditions for pests and increasing the capacity of the crops to compete with one another, these techniques support natural pest management [12]. In short, it's the use of cultural methods or cropping system alteration to manage pests [13]. Reducing the environment's ability to support insect survival and reproduction is the aim of sanitation process.

2.5 Proper Plant Spacing

In Integrated Pest Management, spacing is important for a number of reasons. Proper plant spacing promotes improved air circulation, which lowers humidity levels that might be favourable to pests and diseases. Plants spaced properly dry out faster after rain or irrigation, which reduces the prevalence of diseases that love wetness [14]. While overgrown plants can provide hiding places for pests, making them more difficult to identify and eliminate, it facilitates better pest monitoring and management. Healthy plants that are more resilient to disease and pests may be produced by making sure every plant has adequate room to thrive. By ensuring that plants have sufficient access to nutrients, water, and sunlight, proper spacing can help plants feel less stressed, become less vulnerable to pest infestations and provide a healthy microclimate [15]. This reduces the need for chemical treatments and supports sustainable pest control practices by adding adequate spacing into his integrated pest management (IPM) approach. Plant density has been shown to increase the richness and abundance of natural enemies in the landscape, to facilitate easier escape from disturbance particularly for insects with limited dispersal capabilities, and to increase yield and pest control.

2.6 Tillage

Tillage is an essential component of Integrated Pest Management (IPM) because it facilitates the physical control of weeds, diseases, and pests. By burying pest larvae and exposing them to predators and environments in which they cannot survive, tillage can disrupt the life cycles of pests. Tillage has long been regarded as the finest hygienic method for eliminating weeds. Cook, [16] found that in the no tillage areas pest incidence is more. Tillage reduces competition for nutrients, water, and light by turning the soil and destroying weed beds that are home to pests [17]**.** Conservation tillage techniques, like no-till or strip-till, help preserve soil structure and organic matter while intensive tillage can cause soil erosion and nutrient runoff [18]. This can support healthier crops that are less vulnerable to pests by enhancing the resilience and health of the soil [19]**.** By adding organic matter and fertilizers to the soil, tillage can increase the availability of nutrients for plants. Stronger plant growth and greater pest resistance may result from this. Reduced tillage techniques can aid in the soil's ability to store carbon, which helps mitigate the effects of climate change. Extreme weather conditions are also less likely to affect healthier soils because of their improved structure and higher organic matter content. The depth of the soil and the time of ploughing are important factors to take into account while controlling soil pests. The bugs' immobile stage dictates when to perform tillage, and their position in the soil dictates how deep it must be done [7].

2.7 Pheromone Traps

Pheromone traps are an essential tool in Integrated Pest Management (IPM) for tomatoes. They help monitor and control pest populations by attracting and trapping specific insects using synthetic pheromones. Pheromone traps use synthetic chemicals that mimic the natural pheromones of certain pests, such as the tomato pinworm or the tomato leaf miner. Once the male moths are attracted to the trap, they get caught in a sticky substance or a funnel, preventing them from reproduction. By regularly checking the traps, farmers can monitor pest populations and determine the best times for additional pest control measures. They provide early warning of pest infestations, allowing for timely intervention [20]. Pheromone traps reduce the need for broad-spectrum chemical pesticides by focusing on specific pests. They encourage better crops

and lessen their environmental effect, which supports sustainable agricultural methods [21]. Pheromone traps should be placed at planting, with one trap per 10 acres, but no less than two per field. Twice a week, from planting to harvest, check the traps and remove any insects that are trapped. When you start catching adult pests, start keeping an eye out for larvae on the foliage [22]. Sticky traps had shown higher efficacy in capturing leaf miner compared to delta and water pan traps [23]. Traps were placed at the height similar to the height of the tomato plants. Cutting-edge innovations like automated monitoring systems and smart traps have improved the precision and effectiveness of pheromone trapping [24].

2.8 Sticky Traps

One useful instrument in tomato integrated pest management (IPM) is sticky traps. They catch flying insects, which aids in the monitoring and management of pest populations. The main purpose of sticky traps is to keep an eye on insect numbers. Insects are drawn to and held on a sticky surface by them, keeping them from harming the plants. They can assist in the early detection of pests including leaf miner, aphids, thrips, and whiteflies, enabling prompt action. Sticky traps should be placed at plant height and dispersed equally around the greenhouse or tomato field. This guarantees efficient pest activity monitoring. Because they draw a variety of flying insects, yellow sticky traps are frequently utilized [25]. Farmer may use blue sticky traps particularly to catch thrips [26]. Sticky white traps help lower the number of adult pests. When combined with other IPM techniques like biological controls and selective insecticides, they work best [27,28]. In order to keep sticky traps functional, inspect and replace them on a regular basis [29]. Making educated judgments about pest control and monitoring pest population trends are aided by this. This lessens the need for chemical pesticides and fosters a better crop environment.

2.9 Intercropping

For tomatoes, intercropping is a useful method of integrated pest management (IPM). It entails co-growing various crops to boost overall yield, strengthen soil health, and improve pest control. By drawing beneficial insects that feed on pests, intercropping can aid in the reduction of pest populations. Nematodes and other pests can be avoided by planting marigolds alongside tomatoes. Various crops can enhance the fertility and structure of the soil. When legumes and tomatoes are grown together, the legumes help the tomato plants by fixing nitrogen in the soil. By covering the soil and limiting the amount of area that weeds can grow in, intercropping can inhibit the growth of weeds. Tomatoes and maize can be interplanted to help lower the prevalence of pests like tomato fruit borer [30]. Tomatoes and maize can be interplanted to help lower the prevalence of pests like tomato fruit borer [30]. Less competition results for water and nutrients as a result which reduces pest [31].

Basil enhances tomato flavour and drives away pests like aphids. Lettuce suppresses weeds and grows well in the shade of tomato plants. Onions and garlic are pest-repellent and can be harvested before tomatoes require additional room [32]. The farmer must maintain appropriate spacing to prevent resource competition and rotate the crops to avoid soil erosion and pest accumulation. It is equally important to keep a regular eye out for pests and diseases so one can take quick action. Therefore, a sustainable technique that can greatly increase tomato yield while lowering the need for chemical inputs is intercropping.

2.10 Crop Rotation

Crop rotation is the process of growing several crop sequences on the same plot of land in order to take advantage of the soil's positive function in soil conversion, enhancing soil fertility and structure, and managing weeds and pest. We should avoid planting tomatoes in the same piece of land year after year. If we rotate to a non-host crop than it can significantly scale down the pest population in the plot [33]. As plants develop, tomatoes quickly exhaust the nutrients in the soil. With their massive root systems, they absorb large amounts of nitrogen from the rich soil in which they grow. Over the course of several growing seasons, tomato plants also gather some pests and diseases in the surrounding soil. The same agricultural waste serves as a wintering ground for fungal diseases such as early blight. In the unaltered soil, nematodes grow. When we plant tomatoes in the same spot every year, we are inviting disease outbreaks, weakening plants, and low fruit yield. That whycrop rotation is a very important part of tomato IPM. Crop rotation avoids these issues by interrupting disease cycles and replenishing nutrients. It works by shifting plant families—groups that share nutritional needs and disease

vulnerabilities—to different parts of the garden from season to season. Legumes are highly recommended as an intercrop with tomato because as nitrogen-fixing plants, they restore depleted nitrogen to the soil after heavy-feeding tomatoes. Their roots also aerate the soil and help break up compacted ground. Moreover, legumes don't share common diseases with tomatoes, so they disrupt disease cycles [34].

2.11 Mulching

For tomato plants, mulching is an important part of integrated pest management (IPM). Here are a few main advantages and techniques. By lowering evaporation, mulch helps hold onto soil moisture, ensuring tomato plants always have access to water [35]. Weed seeds are prevented from sprouting by a thick layer of mulch, which lessens competition for water and nutrients. Mulch serves as an insulator, keeping the soil warmer during the cooler months and colder during the hotter ones, which is good for tomato development. Mulch aids in the prevention of soil-borne illnesses by keeping soil off the leaves [36]. Mulch comes in two varieties that are suitable for use: inorganic and organic. Shredded leaves are a good example of an organic mulch since they break down and improve the soil. Herbicides should not be used on straw; it is an effective crop. Grass clippings are easily obtainable and quickly break down, enriching the soil with nitrogen. Tomato-common pests like thrips and tospovirus can be lessened by using inorganic mulches like reflective plastic mulch. Mulch made of landscape cloth aids in moisture retention and weed control. Organic mulches decompose gradually, enriching the soil with nutrients and enhancing its composition.

2.12 Trap Crop

A plant known as a trap crop is one that draws agricultural pests—mostly insects—away from the primary crop. The Indian Institute of Horticultural Research, Bangalore, developed an Integrated Pest Management (IPM) technique that uses African marigold as a trap crop for the management of the fruit borer on tomato [37]. With this technology, 14–16 rows of tomatoes are placed after one row of marigold. The primary crop is spared because marigold flowers draw pests away from the tomato crop. Marigold is a perennial plant that yields a large amount of flowers. Their attention is initially drawn to the fiery colours, which are a palette of vivid autumnal tones. The pollinators would disagree that marigolds' spicy-musky scent is unpleasant to some people. Additionally, marigolds are a plentiful supply of nectar and pollen for our insect friends all through the winter because they bloom continuously, from roughly June until frost throughout the tomato cropping season [38]. The larvae don't have a tendency to migrate to tomato crops and easily feed on the marigold flower [39]. Additionally, the rootknot nematode infestation is lessened by using this trap cropping system [40].

Pests like leaf-footed bugs may be drawn to tomato crops by growing sorghum or sunflower. Farmers may more efficiently target the use of pesticides, lowering the total usage of chemicals and fostering a healthier environment, by concentrating pests on trap crops. Naturally reducing pest populations, beneficial insects like spiders and lad beetles can be drawn to trap crops [41]. The quality and quantity of tomatoes can increase with fewer pests attacking the primary crop, which would boost economic returns [42]. Using trap crops encourages a diverse range of plant and insect species, which maintains ecological equilibrium [43] states that meticulous preparation is needed for the use of trap crops, including choosing the appropriate crop, timing the planting, and strategically placing them around the tomato fields.

2.13 Root Dipping of Tomato Seedlings in Various Chemical Compositions

To protect young plants from pests and diseases, Integrated Pest Management (IPM) commonly involves dipping tomato seedlings' roots in chemicals. An efficient technique is to submerge tomato seedlings' roots in a solution of the systemic pesticide imidacloprid. Aphids and whiteflies are examples of early pests that are controlled by doing this.One of the main factors limiting tomato output is foliar and soil-borne fungal infections. Root dipping of seedling guarantees control of vector-transmitted TLCV and is a crucial part of IPM [44]. Compared to foliar spraying, the seedling dip approach of applying abiotic resistance—such as salicyclic acid and inorganic and organic salts—was more successful in lowering the incidence of bacterial wilt disease [45].

2.14 Use of Botanicals/Bio pesticides

Tomato Integrated Pest Management (IPM) benefits greatly from the use of botanicals as they provide sustainable and environmentally

beneficial substitutes for synthetic pesticides. Botanicals are substances derived from plants that contain bioactive substances like essential oils, terpenoids, alkaloids, and phenolics. These substances frequently serve as plants' defence mechanisms against infections and herbivores. Botanical extracts, when used correctly, can interfere with the behaviour, feeding, reproduction, and development of pests without endangering non-target organisms or releasing harmful organisms into the environment. Because neem extracts work so well against so many different types of pests, they are employed extensively. They serve as growth regulators, antifeedants, and repellents. The leaf miner, whiteflies, and mealy bugs can all be effectively controlled with neem (Azadirachtaindica). (Chrysanthemum cinerariifolium), or pyrethrum, works well against beetles, caterpillars, and aphids [38]. Because of its insecticidal qualities, garlic extracts can help control pests including caterpillars and aphids. Because tobacco extracts include nicotine, they work well against a variety of pests. Extracts from lantana leaves have been proven to be effective in managing pests such as aphids and whiteflies. Another plant utilized for its insecticidal qualities is pongamia oil [46]**.** These plants are not only efficient but also biodegradable [44], less hazardous to the environment and helpful insects [47]**.** Farmers may lessen their need on synthetic pesticides, reducing their impact on the environment and enhancing crop health, by using these botanicals into integrated pest management (IPM) techniques [48]**.**

2.15 Companion Planting to Encourage Beneficial Insects and Predators

For tomatoes, companion cropping is an essential component of integrated pest management (IPM). Some companion plants have the ability to ward off pests or draw in helpful predators. For instance, basil may ward off aphids and whiteflies, while marigold can ward against worms. Pollinators are drawn to flowers like borage and nasturtium, which improves fruit set and production. Beans and other legumes bind nitrogen in the soil, enhancing fertility and promoting tomato development. Low-growing herbs, such as thyme, reduce competition from weeds by acting as a living mulch [49]**.** Certain companion plants can lower the frequency of diseases. Onion intercropping, for example, can aid in the management of fungi-related illnesses like as Verticillium wilt. Farmer may grow a tomato crop that is more robust and productive by planting companion plants strategically [50]. In adds to additional revenue also. The objective is to drawing in beneficial insects, which are the natural predators of unbeneficial garden pests like aphids and caterpillars. Making the most of a growing season and giving insects like ladybugs and beetles the ideal habitat requires careful consideration. Parsley, garlic, borage, squash, asparagus, and chives are some good companion crop for tomato. But anything in the Brassicaceae family—such as cauliflower, cabbage, kohlrabi, kale, and Brussels sprouts—disturbs the growth of tomato plants [51].

2.16 Encourage the Habitat for Natural Enemies

In order to practice efficient Integrated Pest Management (IPM) in tomato agriculture, it is imperative to safeguard beneficial insects and predators. Fruitworms can be effectively combated by parasite wasps. Wasps, lacewings, and other raptors feed on whiteflies. To take advantage of the biological control these species offer, we shouldn't use pesticides. Several species of parasitic flies feed on stink bugs and leaf-footed bugs. Numerous predators, including tiny parasitic wasps, are drawn to the eggs. If pesticides don't scare parasitic wasps away, they serve as a natural control mechanism for leaf miner populations. Numerous natural predators exist for thrips. Biological control is the process of reducing pest populations by introducing natural predators or parasites [52,15] .

We should plant a range of plants around the tomato plants to give helpful insects like ladybugs, lacewings, and hoverflies a place to live and food (pollen and nectar) [53]. Steer clear of broad-spectrum pesticides. Instead, farmers should use insecticides that are targeted at certain pests and do not kill beneficial insects. As discussed above, certain herbs and flowers, including marigolds and basil, can repel destructive pests while drawing beneficial insects. To provide habitats for predators and parasitoids, build shelters like bug hotels or leave some parts of the garden untouched [54]. To maintain a healthy ecology, frequent monitoring on the numbers of beneficial and pest insects is important. Pest outbreaks can be controlled before they get out of control by early detection. Crop rotation and good hygiene should be used to lessen pest pressure and increase the efficiency of natural predators [55]**.** Employ traps, obstacles, and manual extermination to control

pests without endangering beneficial insects. It is crucial to teach workers and farmers the value of helpful insects and how to keep them safe. It is seen that getting trained in IPM techniques can assist guarantee the preservation of beneficial insects.

2.17 Use Pesticides as a Last Resort

Pesticides are used as a last option in tomato integrated pest management (IPM). The IPM method places a strong emphasis on employing a variety of tactics to efficiently control pests while reducing their negative effects on the environment. Environmentally friendly and less hazardous insecticides are employed as a last resort after all other options are exhausted. This strategy lessens the possibility of harm to the environment and public health by ensuring that pesticides are only applied when absolutely required. Regardless of the kind of pest we are dealing with, prevention, early detection, and accurate identification are the first steps in any pest control regimen. The secret is to regularly stroll around the garden and look for pests. The earlier we identify a pest issue, the easier it is to handle. By incorporating beneficial insects into our culture, we can completely prevent a lot of infestations. Among the non-target organisms that pesticides can harm are beneficial insects. Use them as a last resort and only after one have positively identified the pest. Choose pesticides that are least harmful to non-target organisms and the environment.

Effective whitefly population reduction is possible with low impact insecticides such as horticultural oils and insecticidal soaps. An intense stream from the hose can be used to eradicate aphids. We should protect lady beetles and other aphid enemies, maintain the health of our plants, and only use chemicals as a last resort. We might want to trim the plants back if the new growth is stunted in order to get rid of the aphids and the damaged tissues. Bacillus thuringiensis (Bt) and handpicking both work well for tomato fruit worms. Avoid giving your plants too much nitrogen or letting them become water stressed if you want to deter whiteflies. Choosing and eliminating tomato hornworm larvae by hand is a common cultural management technique. Pupae of hornworms die 90% of the time Bacillus thuringiensis (Bt) when injected it is toxic to the larvae of lepidopteran (moth or butterfly). It won't harm beneficial insect. We should use a butterfly net or our hands to remove stink bugs and leaf-footed bugs. Leaf miner damage that is extensive to those leaves should be removed. Thrips are effectively controlled with insecticidal soaps. Soil-borne pests, such as root-knot nematodes, nutsedge and others were controlled by methyl bromide fumigation prior to planting.

2.18 Artificial Intelligence in Tomato IPM

The application of artificial intelligence (AI) to tomato integrated pest management (IPM) is revolutionizing the field. AI is utilized to accurately identify and categorize tomato diseases, especially when it comes to deep learning models. For example, TomatoDet and other models use sophisticated feature extraction and self-attention techniques to detect illnesses like leaf mold, brown rot, late blight, and gray leaf spot [56]. Tomato crops may be continuously monitored by AI-powered devices, which can take pictures and analyse them to look for indications of illness or insect infestation. These technologies can give farmers feedback in real time, allowing for prompt interventions [57]. Artificial Intelligence has the ability to forecast possible pest or disease outbreaks by evaluating past data and environmental factors. As a result, farmers are able to take preventative action and depend less on chemical pesticides [58]. AI provides accurate information on crop health, soil conditions, and pest prevalence by integrating with other technologies like as drones and IoT sensors. This promotes increased crop output and resource efficiency [59].

2.19 Some Recent IPM Techniques

There are a few modern tomato-related Integrated Pest Management (IPM) methods: farmers have automated traps which can do real-time pest population monitoring by using smart traps that are fitted with sensors and cameras. Remote sensing can be utilized by using satellite imagery and drones to find pest outbreaks and tomato crop stress. Innovations in biological control has also taken place by way of RNA Interference (RNAi) which targets particular genes in pests to lessen their capacity to harm crops. Even there are evolution of enhanced beneficial insect producing and dispersing more potent strains of predatory mites and parasitic wasps, two examples of natural predators. To increase resistance to soil-borne pathogens, tomato plants can be grafted onto rootstocks that are resistant to disease. In the integrated weed management front, solarization can be done

before planting. The soil is heated by solar radiation to destroy soil-borne pathogens and weed seeds. Mulching with biodegradable films lowers the need for herbicides by suppressing weeds with biodegradable mulch films. Putting decision support tools like IPM Decision Support Systems (DSS), that combine crop growth stages, pest models, and meteorological data to provide real-time pest management advice are also being extensively used. The purpose of these techniques is to improve tomato cultivation pest management's sustainability and efficacy.

2.20 Constraints in Implementing IPM Strategy

To control the growing use of pesticides in agricultural output, integrated pest management, or IPM, is suggested as a substitute for traditional pest management techniques. However, there are several difficulties in implementing IPM. Efforts to put IPM practices into practice have entailed addressing problems that are intimately related to information, training and knowledge systems, social and psychological aspects, policy, and extension techniques. Promoting the use of Integrated Pest Management (IPM) requires enabling policies on pest management tactics, as evidenced by repeated successes [60]. It is essential that the government has the good will to encourage alternative pest management strategies with policies. Propagating the use of IPM will be impossible until clear policies are established. Farmers in particular are resistant to new technology and practices, thus it's important to take social and psychological barriers into account when putting IPM practices into practice. New technology delivery is essential, and IPM's participatory character necessitates a paradigm shift in extension techniques. Implementing IPM is also hampered by knowledge and training gaps, which mostly affect farmers and extension professionals. The difficulties in implementing IPM have an impact on extension groups' ability to teach farmers about the new methods. However, in order to effectively address the issues facing IPM, extension organizations require assistance from other stakeholders and cannot act alone. The obstacles that must be removed before farmers can embrace IPM practices [61] .

3. CONCLUSIONS

Careful timing and long-term planning are needed for maximum effectiveness. To successfully adopt different components, one must have knowledge of the biology, ecology, phenology, and relationships/interactions of crops and pests. For IPM programs to be implemented successfully, all stakeholders and the most forward-thinking growers must be included. Good educational materials, advice on pest management, and biological control agents should also be provided. Research on IPM techniques under local environmental conditions and their subsequent use at the farmer's field level has become imperative for all involved stakeholders. This paper increases the demand for in-depth, specialized publications on each technique and broadens the area of research on various strategies under Integrated Pest Management in various field settings.

Crop-related diseases, weeds, and pests pose a major risk to agricultural livelihoods, food security, and poverty alleviation initiatives. There are several methods to use IPM techniques to reduce harm. IPM is updated for modern times, when advanced agricultural technology is essential to the production and consumption of food. IPM is much more than just a standard method of conserving resources. Like other sustainable intensification strategies, IPM approaches necessitate a high level of understanding. Technology breakthroughs have now opened a new chapter in IPM. After all, this method is not without its restrictions. Extension officers should have received more IPM training. Farmers will be better able to manage pests and produce more crops as a result of this. For this, government aid is required. IPM will reach a new peak if digital technology is used with the present pest management strategy. IPM guidance is required to assist sustainable agricultural practices that balance consumer affordability, crop farmer income, food security, and environmental preservation for the world's growing population.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://prh.mbimph.com/review-history/4034