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Socioeconomic Factors Affecting IPM Adoption

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Abstract

Integrated Pest Management (IPM) is a comprehensive, science-driven strategy for controlling pests that employs multiple methods to either prevent pest issues or minimize their impact. Instead of relying solely on one technique, an effective IPM plan combines various pest control tactics. Various factors influence the uptake of Integrated Pest Management (IPM) such as Political factors government plays a key role in encouraging, overseeing and regulating the creation, distribution and usage of pest-control products, Technological factors research institutions and industry often lack the scientific expertise and technical capacity to innovate, test and commercialize biopesticides effectively, Socioeconomic factors without large-scale manufacturing, the production and supply of biopesticides remain limited, keeping costs high and restricting wider access. Indian condition the major influence on IPM and biopesticide adoption including small-land holding, family labor, educational status, limited access to technology, government dependency (support policies), lack of organized extension services. Community and social structures like local cooperative society, self-help groups and community networks often provide support and resources plays a vital role in acceptance of IPM. Government and institutional support structure improvements to utilization of IPM incorporation with conventional aged old cultivation practices for adoption of IMP and biopesticide through conducting farmers' school, on and off field demonstration, hands on training and innovation in the sector of cost minimization of biopesticide production.

Keywords Biopesticides, Digitization, IPM, Pest control, Socioeconomics, Training

1. Introduction

RJ Prokopy (2003) well-defined integrated pest management (IPM) as '…a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner'. According

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to Ehler (2006), an IPM practitioner is responsible for the following:

- Instantaneous management of multiple pests.
- Regular monitoring of pests and their natural.
- Enemies and antagonists as well.
- Use of economic or treatment thresholds when applying pesticides.
- Integrated use of multiple, suppressive tactics.

Integrated Pest Management (IPM) refers to the approach of preventing or reducing harmful insect populations through a well-coordinated and comprehensive use of multiple control methods. These methods can include chemical, biological and cultural tactics. Strategies involve planning and implementing these control methods in a way that balances their economic, environmental and social impacts. While IPM is an all-encompassing philosophy, it is fundamentally grounded in applied ecology. The deliberate, targeted control of plant pests underpins Integrated Pest Management (IPM), serving as its essential foundation. This strategy ensures that agricultural yields remain robust while safeguarding both economic viability and environmental health (Rossi *et al.*, 2019). A cornerstone of IPM is the continuous monitoring of pests, applying treatments only when populations reach predefined action thresholds (*i.e.*, the minimum pest population abundance that justifies the application of a treatment) and using pesticides judiciously and sustainably. According to Barzman coauthors, IPM is based on eight principles:

a) Prevention of pest occurrence and suppression of pest populations.

b) Monitoring of harmful pests.

c) Informed decision-making.

d) Priority to non-chemical methods.

e) Multi-criteria selection of pesticides.

f) Pesticide use reduction.

g) Voidance of pests resistance to pesticides.

h) Evaluation.

2. Bibliometric Analysis

Bibliometric analysis is a key research method that uses quantitative metrics like citations and collaboration networks to assess the impact of scholarly publications, authors and journals. Available literature on socioeconomic factors affecting IPM adoption was reviewed. A web-based search engine was used with the filter: "Factors AND Affecting AND IPM AND Adoption" for the years 2000-2024. A total of 58 scholarly works were found, with 5 citing patents and 2,765 scholarly citations (Figure 1).

Another filter was applied: "Socioeconomic AND Factors AND Affecting AND Integrated AND Pest AND Management", which yielded a total of 323 scholarly works, 29 citing patents and 15,095 scholarly citations for the period 2000-2024. The regional focus of the literature was India (Figure 2).

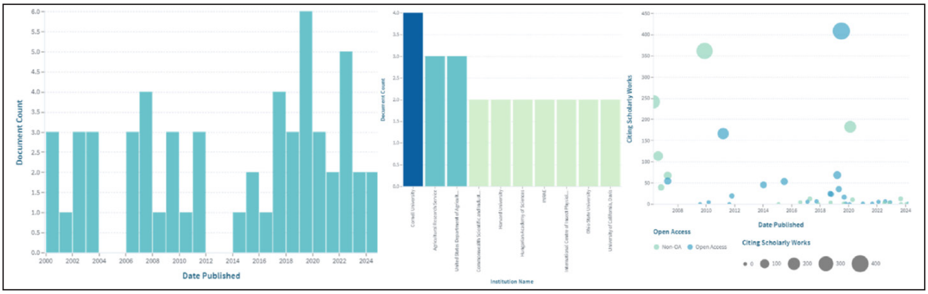

Figure 1: Literature review against socioeconomic factors affecting IPM adoption. Work over time, top institutions and citation, year 2000-24

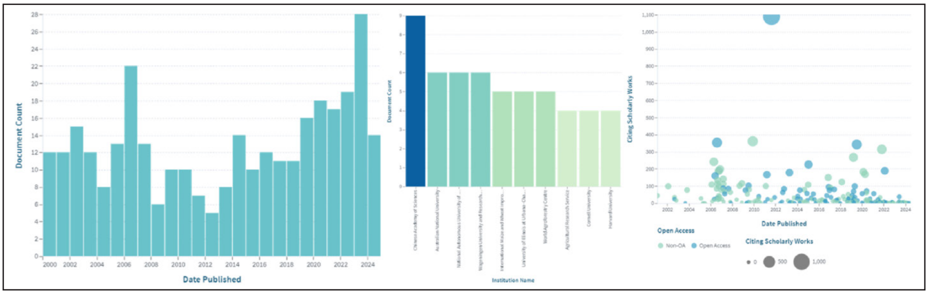

Figure 2: Literature review against socioeconomic factors affecting IPM adoption. Work over time, top institutions and citation, year 2000-24; Filter: "economic AND importance AND biological AND control"

From the year 2000-2009, a total of 123 papers were published, followed by 104 papers during 2010-2019 and 96 papers in the period 2020-2024, globally (Table 1).

Table 1: Total of 323 articles published during 2000-24, filter: journal article

Publication Year	Document Count	Publication Year	Document Count	Publication Year	Document Count
2000	12	2010	10	-	-
2001	12	2011	7	-	-
2002	15	2012	5	-	-
2003	12	2013	8	-	-
2004	8	2014	14	-	-
2005	13	2015	10	2020	18
2006	22	2016	12	2021	17
2007	13	2017	11	2022	19
2008	6	2018	11	2023	28
2009	10	2019	16	2024	14
Total	123	Total	104	Total	96

3. Decision Making

IPM decision-making encompasses interconnected strategic, tactical and operational layers, reflecting the intertwined complexity of long-term planning, medium-term methodology and immediate action. Integrated Pest Management (IPM) decision-making operates across three interconnected levels:

Strategic Level: Involves long-term planning, such as determining crop rotation schedules and selecting appropriate plant varieties to enhance pest resistance.

Tactical Level: Focuses on mid-term actions, including selecting pest control methods and implementing them based on current crop conditions, like addressing a disease outbreak.

Operational Level: Entails immediate responses to dynamic field conditions, such as adjusting treatments according to canopy size or unforeseen events like rainfall that may delay pest control measures (Figure 3).

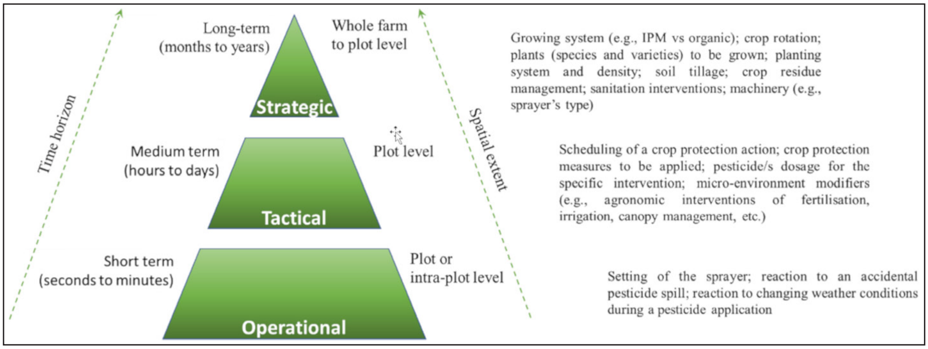

Figure 3: Association between the decision-making process and the category of operation in integrated pest management (IPM) at numerous spatio-temporal scales.

4. Decision Tools for IPM

From 1980, an increasing rate of DTs is established for supporting farmers, practitioners and farm managers in their decision-making at various spatio-temporal scales. In the European Union (EU), for example, some concentrated actions (*e.g.*, the European network for operational and tactical DSS on crop protection (EU.NET.DSS) and European cooperation in science and technology (EU-COST) actions are specifically reinforced for inspiring both the development and introduction of this new information technology as a common initiative). The epidemic prevention (EPIPRE) system for supervised integrated control of wheat diseases represented one of the earliest practices of a computer-based advisory system in Europe (Rabbinge and Rijsdijk, 1983). These DTs have been technologically advanced and/or improved by:

i) Public research and extension services.

ii) Plant protection organizations.

iii) Private companies/groups marketing products or services or providing consultancy to farmers.

DT includes also the support at:

i) Preserving the status of the agro-ecosystem.

ii) Reducing the use of external inputs (*e.g.*, plant protection products).

iii) Enhancing crop yield and quality.

iv) Meeting government and community expectations about landscape management.

v) Ensuring access to markets characterized by high standards related to environmental safety and product quality.

Accessibility of the DT is simple for individuals to use (Cox, 1996). The following is a list of some of the most important necessities a DT software should satisfy to assurance user-friendliness:

a) Learning Time: Use of the DT based on simplicity of the instruction manual and limitation of the time requirements for learning. The strategic organization of training, seminars, workshops and incessant support to users (*e.g.*, through extension services/activity and experts/professionals) may facilitate the long-term acceptance of DTs.

b) Time spent for circumnavigating in the DT to get the information derived systems. Some DTs are time overwhelming because of tedious input supplies or delays in data processing and evaluation. The time petition on the user has been documented as a paramount element in causal the acceptance of DTs.

c) Timely Information: The timely manner of provision of information to be effective within the decision-making development. For example, decisions about the management of grape downy mildew (*Plasmopara viticola*) are taken every 12 h during the most dangerous periods of the crop period.

d) Time Spent for Input Requirements: Relevant data provision inputs to DTs are frequently linked to: (i) Agro-meteorology; (ii) crop production and phenology; and (iii) pest presence and abundance.

e) Clarity of the Output: This is a vital point for the acceptance of a DT. Nowadays, most of the DTs are delivered through web-platforms or applications participating a user-friendly graphical user interface (GUI) allowing the user to navigate and evaluation within the DT and refer the main outputs and commendations.

5. Determination of Influencing Factors for IPM

Talukder *et al.* (2017) assessed logistic regression-based (LR) methods for resolve of socioeconomic factors for IPM implementation and study variables such as adoption status of IPM (1, if adopt IPM; 0, otherwise) is considered for the main contributing variable of attention. A farmer is classified as an IPM (Integrated Pest Management) farmer if they have recently adopted IPM practices; otherwise, they are considered a conservative farmer (Figure 4). In addition to this primary classification, several other factors are considered as potential influences on the adoption of IPM (as shown in Table 2). These include the farmer's age (grouped into five categories), education level (no or primary education, secondary, or higher education), geographic division, farming experience (categorized as at least 10 years or more than 10 years), farm size (divided into three categories based on the area of cultivated land), farm ownership (yes or no), whether the farmer has received IPM training

Table 2: Crop and biopesticides adoption by farmers and different target pest and crop

Sl. No.	Target	Region	Influencing factors/variables	Authors
1	Vegetable farmers	Sri Lanka	• Removal of leftover crop materials after harvest • Implementation of crop rotation techniques • Conservation and support of beneficial natural predators • Application of soil treatment methods • Use of chemical fertilizers at the recommended rates • Adoption of non-chemical methods for weed control • Management of pests through physical means • Utilization of traps and baits for pest control • Adoption of mixed cropping practices	
2	Smallholder Tomato farmers	Kenya	• Farmer's gender and size of landholding • Availability of agricultural labor • Access to agricultural knowledge and resources • Farmer's age	Kihoro *et al.* (2021)
3	Soybean	Brazil andUSA	• Farmers' concern about major yield losses if insecticides aren't used, leading to hesitation or refusal to fully implement economic threshold (ET) practices • The considerable labor and time needed for regular insect monitoring	Bueno *et al.* (2021)

Sl. No.	Target	Region	Influencing factors/variables	Authors
4	-	-	Technological constraints: Technological advancements, such as increased access to personal computers, the internet and web-based services, have addressed many of the key barriers to adopting decision tools (DTs) in agriculture. Socio-Economic constraints: i) The simplicity and quickness of mastering the new tool ii) The involvement of end-users in enhancing the perceived benefits of adopting it	Rossi *et al.* (2019)
5	Adoption of biopesticide	Nigeria	• Political: The government's role is to encourage, regulate, or oversee the creation, distribution and use of manufactured products within the country. • Technological: Both academia and industry lack the necessary scientific expertise and technical skills to research, develop and commercialize biopesticide products. • Socioeconomic: The high cost of producing and purchasing biopesticide products is due to the absence of industrial-scale production.	Ivase *et al.* (2017)
6	Farmers' decision to IPM	Bangladesh	• Age of respondents (grouped into five categories) • Level of education (no/ primary education, secondary, higher) • Years of farming experience (more than 10 years) • Farm size (divided into three categories based on the cultivated land area) • Participation in IPM training • Membership in an IPM club • Attendance at Farmer Field School (FFS)	

Sl. No.	Target	Region	Influencing factors/variables	Authors
7	Small-scale Vegetable Farmers	DR Congo	• Gender (1 = male, 0 = female) • Age of farmers (years) • Farmer's main Profession (1 = farmer, 0 = Other) • Farmer's education (1 = primary, 2 = high school, 3 = university, 4 = professional) • Farmer attended training (Yes = 1, 0 = no) • Membership to a farming association (Yes = 1, 0 = no) • Farmer's Years in farming(years) • Land access(1 = location, 0 = other modes) • Land size • Experienced pesticide problems (yes = 1, 0 = no) • Market requierement (yes = 1, 0 = no) • Pesticide cost in US Dollar	Balasha *et al.* (2019)
8	Potato farmers	Carchi, Ecuador	• Alternative dissemination methods • Farmer field schools (FFS) • Field days • Pamphlets • Word-of-mouth transmission	Mauceri *et al.* (2007)
9	-	Nepal	The analysis is divided into three main categories: socio-demographic, economic and institutional factors. The dependent variable is categorized into levels: none, low, medium and high. • None adoption indicates that the farmer does not use any IPM practices. • Low adoption means that the farmer has adopted one IPM practice. • Medium adoption indicates that the farmer has adopted two IPM practices. • High adoption means that the farmer has adopted three or more IPM practices.	Khanal *et al.* (2020)

Sl. No.	Target	Region	Influencing factors/variables	Authors
10	Wheat, maize, sugar beet, sunflower and soya	Serbia	• Gender (male = 97.8% and female = 2.2%) • Age (20-82) • Education (elementary school (11%), high school (73.5%) and university (15.5%) • Farm size (10-200 ha) • Environmental knowledge (0-9) • Pesticide use (yes/no) • Biological pest control adoption (yes/no) • Contact with extension service (yes/no)	Despotović *et al.* (2019)
11	Wheat	Iran	• Age • Level of literacy • Years of farming • Annual on-farm income • Annual off-farm income • Farm size • Level of participation in extension - education courses • Using level of information sources and communication • Channels • Level of awareness about the effects of IPM practices • Viewpoint on extension agents • Level of knowledge about IPM practices	Samiee *et al.* (2009)
12	Cereal, legume and vegetable	Kenya and Uganda	• Household demographics and farm traits •v Understanding of pests affecting target crops and their management methods • Household concerns regarding health and environmental impacts of pesticide use • Farmers' knowledge, views, information sources and willingness to pay (WTP) for biopesticides	Nyangau *et al.* (2020)

Sl. No.	Target	Region	Influencing factors/variables	Authors
13	Adoption of biopesticide	Cotton Bollworms	Variables in the Econometric Model for Biopesticide Adoption • Efficacy (1 = Willing to pay US$1 or more for the biopesticide; 0 = Willing to pay less than $1) • Agro-ecological zone (1 = Farmers from the northern province of Benin; 0 = Farmers from the central region) • Age (Age of the farmer) • Education (Educational level of the farmer) • Gender (Gender of the farmer) • Contact (Frequency of visits by extension officers to the farmer) • Pest intensity (Farmer's perception of the current pest pressure on cotton) • Mode of action (How the biopesticide functions)vv	Adetonah *et al.* (2008)

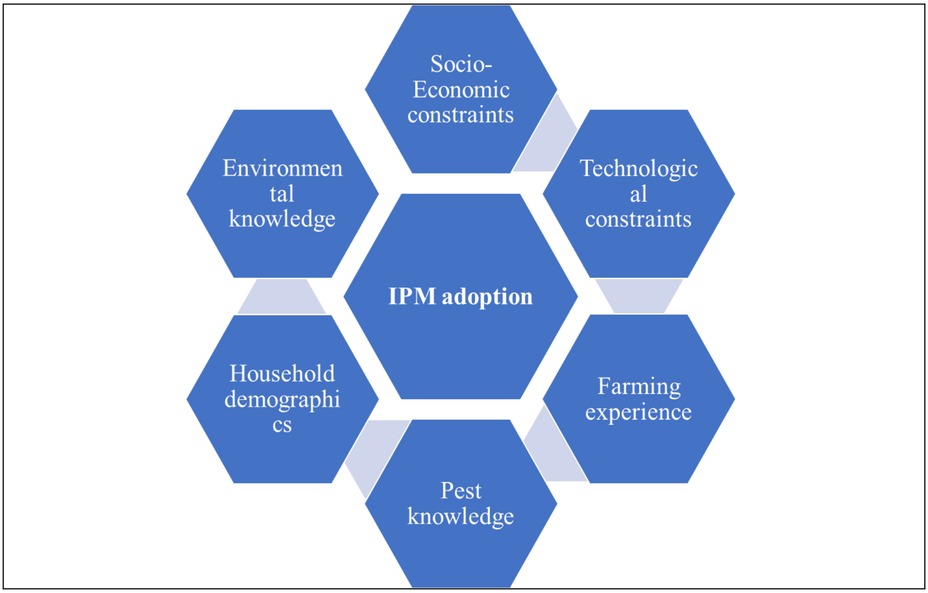

Figure 4: Factors influencing IPM adoption by farmers

(yes or no), membership in an IPM club (yes or no) and participation in a Farmer Field School (FFS) program (yes or no).

Empirical and mechanistic models are among the most effective tools for supporting decision-making in Integrated Pest Management (IPM):

• Empirical (data-driven) models use data to identify and formalize relationships through mathematical or statistical methods (*e.g.*, linking pest population levels with air temperature). These models offer valuable insights for uncovering associations within a system that are either unknown or not well understood.

• Mechanistic, or process-based, models describe processes, such as pest population dynamics or disease outbreaks, based on the fundamental functional parameters that drive them. These models are essential for assessing biological responses as functions of one or more environmental variables (*e.g.*, air temperature, relative humidity, *etc.*).

Based on the results of the logistic model, there is strong evidence that older farmers are more likely to adopt IPM practices compared to their younger counterparts. Farmers with higher levels of education also show a greater likelihood of adopting IPM, likely due to their increased awareness of the harmful impacts of chemical pesticides and fungicides on human health and the environment. Additionally, those with more farming experience and those who have received IPM training are more inclined to implement IPM techniques for pest management. The model-based analysis highlights that age, education, farming experience and IPM trainings are highly significant factors influencing the adoption of IPM practices (Talukder *et al.*, 2017).

6. Major Influencing Factor Affecting IPM in India

1. Economic Considerations: Farmers' financial constraints can impact their ability to invest in IPM practices. Cost-effectiveness and the potential for increased yields and reduced losses play a significant role in adoption.

2. Knowledge and Farmers Training: Access to education and training about IPM techniques is crucial. Extension services and educational programs can help farmers understand and implement IPM practices effectively.

3. Availability of Resources: The availability of necessary resources, such as pest-resistant crop varieties, biological control agents and appropriate tools, affects the adoption of IPM. Limited access to these resources can hamper implementation of IPM.

4. Government Policies and Funding: Government initiatives and subsidies that promote IPM practices can significantly influence adoption rates. Supportive policies and financial incentives can encourage farmers to adopt IPM strategies.

5. Cultural Practices: Traditional farming practices and local knowledge influence how new methods are received. IPM practices may need to be adapted to fit within existing cultural and agricultural frameworks.

6. Pest Occurrences and Crop Type: The level of pest pressure and the type of crops grown can impact the adoption of IPM. High pest pressures or specific crop requirements may drive the need for more targeted IPM approaches.

7. Marketing Strategies: Access to markets and consumer demand for sustainably produced products can motivate farmers to adopt IPM. Farmers may be more inclined to use IPM if it aligns with market preferences for eco-friendly produce.

8. Climate and Environmental Factors: Local climate and environmental conditions influence the effectiveness and feasibility of IPM practices. IPM strategies need to be tailored to specific environmental contexts to be successful.

9. Social and Community Factors: Influence and community support play a role in the adoption of IPM. Farmers may be more likely to adopt IPM if they see successful examples within their community.

10. Research and Development: Ongoing research and development contribute to the refinement and effectiveness of IPM practices. Innovations and improvements in IPM methods can enhance their adoption and implementation.

Under Sri Lankan conditions, IPM has demonstrated a 50% reduction in pesticide use for chili and an 80% reduction in pest control costs, while also resulting in a 20% increase in profits from cabbage production. However, about 47% of farmers routinely apply chemical pesticides before pests or diseases even appear in the field, with only 2% following the 'economic threshold level' concept. In terms of pesticide application, 60% of farmers adhere to the recommended dosage. Despite being aware of the negative effects of mixing agrochemicals, 46% of farmers continue this practice. The term "IPM" is recognized by 44% of the sample, but only 20% of farmers have a clear understanding of the IPM techniques.

The adoption of IPM techniques among vegetable farmers remains unsatisfactory. Practices such as 'destruction of crop residues' and 'soil treatments' are fully adopted by 91% and 93% of farmers, respectively. 'Non-chemical weed management' and 'crop rotation' are also commonly adopted, with 77% and 66% of farmers following these practices. While some farmers also fully adopt 'non-chemical pest management' and 'mixed cropping,' practices like 'protecting natural pest enemies,' 'using traps and baits,' and 'proper inorganic fertilizer management' are adopted correctly and consistently by only a few.

In relation to practices like destruction of residues, soil treatment, non-chemical weed management, crop rotation and mixed cropping, over 50% of farmers follow these practices without fully understanding their benefits. However, 25% of farmers have a solid understanding of non-chemical pest management and 15% are knowledgeable about traps and baits. Only 5% of farmers have received formal IPM or non-chemical pest management training, with others acquiring knowledge through experience or from neighboring farmers (Jayasooriya and Aheeyar, 2016).

Kihoro *et al.* (2021) assessed the socioeconomic factors influencing the adoption of Integrated Pest Management (IPM) among smallholder tomato farmers in Kenya, focusing on 2,450 small-scale farmers. The study considered factors such as gender, farm size, labor availability, access to information and age of the farmers. A comparison between IPM adopters and non-adopters showed that IPM adopters had an average yield of 35 tons per acre, compared to just 25 tons per acre for non-adopters (Table 3).

Table 3: Comparison of yields, net returns and cost of production between an IPM adopter and a non-IPM adopter of tomato farmers (Kihoro *et al.*, 2021)

Variables	Adopters	Non adopters
Average yields per acre (tonnes)	35	25
Average Net returns per acre (Rs.)	592,000	422,500
Average cost of production per acre (Rs.)	250,000	300,000

The application of IPM led to higher long-term returns at the farm level, as excessive use of chemicals does not harm soil microorganisms. A regression-based model revealed that gender (5%), farm size (5%), access to hired labor (5%), access to information (5%) and age of the farmer were statistically significant factors. The study found that males were 43% more likely to adopt IPM than females. Interestingly, access to information had a negative and significant impact on IPM adoption in tomato production, indicating that increased access to information led to a 40% increase in IPM adoption.

Stern *et al.* (1959) defined the economic injury level (EIL) as the lowest pest population that can cause significant economic damage to plants. However, pest management is typically applied before reaching the EIL to avoid economic losses. The appropriate time to begin pest control to prevent the pest population from reaching the EIL is known as the economic threshold (ET) (Pedigo *et al.*, 1986). Bueno *et al.* (2021) explored the challenges of adopting Integrated Pest Management (IPM) in soybean farming in Brazil and the USA, identifying two main challenges. The first challenge is the reluctance to adopt economic thresholds (ETs) and the second is the need for easier and faster sampling procedures. They assessed and compared the socioeconomic factors in two contexts: the small farm scenario in Paraná State, Brazil, where IPM was adopted over six crop seasons and the large farm scenario in Mato Grosso State, Brazil. Key challenges for soybean farmers include areas with high rainfall, such as in Mato Grosso, where precipitation exceeds 2,000 mm per year. In these regions, it is often challenging to wait for the ET to be reached before applying pest management due to the risk of prolonged rainfall that delays insecticide applications. However, rainfall can also negatively impact insect populations through physical control, changes in insect behavior, or by creating favorable conditions for entomopathogenic diseases. Furthermore, EILs and ETs are determined in small research plots, which may not accurately reflect field conditions. Lastly, the operational complexity for farmers practicing IPM is greater than for those who follow a fixed spraying schedule, as IPM requires spraying based on scouting and ETs. Non-IPM farmers typically schedule spraying based on herbicide and fungicide needs and a fixed calendar, simplifying their operational planning.

Biopesticides refer to pest control methods that use bioactive microbes from plant and animal sources for sustainable crop protection. They are biodegradable alternatives to synthetic insecticides commonly used for controlling pests and diseases both pre- and post-harvest. The chemical pesticide lindane was first introduced in Nigeria in the early 1950s and the widespread use of chemical pesticides increased as a response to the need for higher agricultural productivity and crop yields driven by urbanization and population growth. The government plays a key role in stimulating, regulating and overseeing the development, distribution and use of manufactured products in the country. Biopesticides are made from a wide range of living and non-living entities, which vary greatly in terms of properties, modes of action, composition and behavior in their environments. Therefore, the government must implement strict health, safety and environmental monitoring regulations before approving biopesticide production and handling.

Technologically, biopesticide development in Nigeria faces challenges, primarily due to a lack of research and development infrastructure. Both academia and industry lack the scientific expertise and technological capabilities needed to research, develop and commercialize biopesticide products. Additionally, biopesticides struggle to compete with synthetic pesticides on cost, leading to low market penetration and availability. The high costs deter farmers, limiting the acceptance of biopesticides despite their potential benefits. This situation strengthens the first-mover advantage of synthetic pesticides in pest management. However, the lack of technological leadership in biopesticides also presents numerous opportunities for sustainable agricultural practices (Ivase *et al.*, 2017).

Talukder *et al.* (2017) explored the factors influencing farmers' decisions to adopt IPM. The study collected socio-economic and demographic data from 617 farmers across five divisions in Bangladesh (Dhaka, Chittagong, Rangpur, Khulna and Barisal). A random sample of 450 conventional farmers (who use chemical pesticides) and 167 IPM farmers (who have recently adopted IPM) was interviewed. The results showed that the adoption rate of IPM increases with the age of the farmer, indicating that older farmers are more likely to adopt IPM than younger farmers. Among educational groups, those with higher education were more likely to adopt IPM (44.2%), compared to about 24% in the other two groups. Farmers from Barisal were most likely to adopt IPM (37%), while those from Khulna had the lowest adoption rate (21.7%). Among IPM adopters, 29.5% had more than 10 years of farming experience, 39.6% had more than 1.5 acres of cultivated land, 28.7% owned their farms, 30.3% had received IPM training, 28.3% were members of an IPM club and 29.5% participated in farmer field schools (FFS).

A field survey of 246 vegetable farmers in Lubumbashi, DR Congo, was analyzed using a logistic regression model to identify the factors influencing the adoption of Integrated Pest Management (IPM) techniques. The results showed no significant differences between gender and the willingness to adopt IPM. However, a larger proportion of female farmers (46.6%) expressed interest in testing new IPM techniques without hesitation. Membership in a farmer's group (Association) and prior agricultural training had a positive and significant impact on IPM adoption, increasing the likelihood of adoption by 4.2 and 7.7 times, respectively. Additionally, farmers who had previously observed the negative effects of pesticides were 5.2 times more likely to adopt alternative pest control methods (Balasha *et al.*, 2019).

Mauceri *et al.* (2007) examined the effectiveness of IPM dissemination techniques among potato farmers in Carchi, Ecuador. The study analyzed various factors influencing IPM adoption, including: (1) the spread of information and sources of information related to IPM adoption and knowledge, (2) determinants of participation in Farmer Field Schools (FFS) using a probit model, (3) determinants of IPM adoption using an instrumental variables (IV) regression and (4) the cost-effectiveness of different diffusion mechanisms. The descriptive analysis categorized farmers into three groups: (1) FFS participants, (2) farmers exposed to FFS graduates and (3) random farmers with no known connection to FFS or its participants. The adoption of IPM varied based on the information source. About 42% of farmers had moderate to high adoption (Categories IV and V), 37% had low to moderate adoption (Categories II and III) and 20% did not adopt any IPM practices (Category I).

Khanal *et al.* (2020) assessed the factors influencing the adoption of Integrated Pest Management (IPM) technology among farmers in Nepal. The determinants included in the model were categorized into three main groups: socio-demographic, economic and institutional characteristics. Five variables were found to be statistically significant at the 1% level for practicing IPM technology: experience, training, membership in a farmer's group (MPC), mass media exposure and participation in Farmer Field Schools (FFS). At the 5% level, the following variables were statistically significant: awareness of pesticide alternatives and attending field days. Age was statistically significant at the 10% level for practicing IPM technology. Seven other variables, including gender, total family size, education, farm size, extension agent, access to credit and visits, were found to be statistically non-significant.

The study identified five key practices used to define the dependent variable for IPM adoption, which include soil amendment, mulching, bagging, soil solarization, pheromone traps, biofertilizers, bio-pesticides, jholmol and grafting. The variables were categorized as follows:

Category I: Socio-demographic Characteristics

- Age: Farmer's age
- Gender: Farmer's gender (Female = 1, Male = 0)

• Total family member: Number of family members in the household

• Education: Farmer's education level

• Experience: Years of farming experience

Category II: Economic Characteristics

• Farm area: Total size of the farm area (including owned, rented and leased land)

Category III: Institutional Characteristics

• Training: Access to IPM training

• Extension agent: Distance (km) to the nearest extension agent

• Credit: Access to credit

• Awareness: Awareness of pesticide alternatives

• MPC: Membership in a farmer's group (MPC)

• Mass media: Exposure to mass media for information

• FFS: Participation in Farmer Field Schools organized by DADO, IPMIL, or other organizations

• Visit: Participation in visits organized by CBFs or agricultural officers

• Field day: Participation in field day demonstrations organized by CBFs or agricultural officers

Despotović *et al.* (2019) aimed to identify the main factors influencing farmers' behavioral changes towards adopting more environmentally friendly agricultural practices in Serbia. Specifically, the study analyzed farmers' intentions to adopt Integrated Pest Management (IPM) practices (Table 4). IPM is a farming approach designed to control pest populations in a cost-effective and environmentally sustainable way. The study's estimates provide statistical evidence addressing two key research questions:

i) What role does attitudes, subjective norms, or perceived behavioral control play in explaining farmers' intentions to adopt IPM?

ii) Do other farming characteristics influence farmers' intentions to adopt IPM?

Samiee *et al.* (2009) studied the factors affecting wheat growers in Iran with three main objectives: (1) to examine the socio-economic profile of wheat growers, (2) to determine the adoption level of Integrated Pest Management (IPM) practices among wheat growers and (3) to explore the factors associated with the adoption of IPM practices. The selected variables for the study included age, literacy level, years of farming experience, annual on-farm and off-farm income, farm size, participation in extension education courses, use of information sources and communication channels, awareness of the effects of IPM practices, farmers' views on extension agents and their knowledge of IPM practices for managing insects, diseases and weeds. The frequency distribution of wheat growers regarding IPM practices adoption was classified into the adoption levels of insect IPM practices, disease IPM practices, weed

Table 4: Farmers attitude towards IPM and biopesticide adoption
IPMA (Attitudes towards the adoption of IPM)
IPMA1: Reducing the use of pesticides negatively affects the farm profit. IPMA2: By reducing the use of pesticides, I would improve the soil quality on my farm. IPMA3: Farmers in my surroundings should reduce the use of pesticides in order to pollute soil less.v
IPMSN (Subjective norms towards the adoption of IPM)
IPMSN1: People whose opinion I value recommend the biological pest control. IPMSN2: Farmers similar to me mostly use pesticides to reduce production and economic risks in production. IPMSN3: Farmers in my surroundings generally do not apply biological pest control.
IPMPBC (Perceived behavioral control towards the adoption of IPM)
IPMPBC1: The use of pesticides is the easiest way to combat pests, diseases and weeds. IPMPBC2: Biological pest control is not well known to me. IPMPBC3: Nothing prevents me from applying biological pest control.v
IPMI (Intentions towards the adoption of IPM) IPMI1: I plan to reduce the use of pesticides this year. IPMI2: I intend to reduce the use of pesticides over the next 5 years. IPMI3: I will regularly try to reduce the use of pesticides in the future.

IPM practices and overall IPM practices. Independent variables analyzed included the use of information sources and communication channels, awareness of the environmental benefits of sustainable practices, farmers' views on extension agents and knowledge of sustainable IPM practices. About 15.3% of the respondents expressed a low opinion of the change agents, while only 5.8% of wheat growers had a high opinion of them.

Nyangau *et al.* (2020) examined household demographic characteristics in Kenya and Uganda with a focus on crops such as cereals, legumes and vegetables. The study considered variables like the age of the household head, sex, education level, annual income, household size and the distance to the nearest pesticide market. In Kenya, key factors influencing willingness to pay (WTP) for *Bt* included awareness of the negative effects of chemical pesticides, trust in community members and risk attitude. In Uganda, factors such as the household head's age, sex, education level, income, household size, awareness and risk attitude were the primary determinants. For WTP for *M. anisopliae* in Kenya, sex, education, awareness, trust and risk attitude were significant, while in Uganda, age, sex, awareness and risk attitude played a major role. Age was found to negatively impact WTP for both *Bt* and *M. anisopliae* in Uganda, meaning older individuals had a lower willingness to pay.

Adetonah *et al.* (2008) assessed the willingness to pay for Metarhizium-based biopesticides to control cotton bollworms in Benin. A sample of 400 conventional and organic cotton producers was randomly selected. The results revealed that the price premium farmers were willing to pay ranged from 14% for conventional cotton growers to 37% for organic cotton farmers. The study simulated various scenarios, including yield increases and reductions in pest control costs, to gauge farmer interest. Both groups of cotton producers showed interest in using Metarhizium to control *Helicoverpa* on cotton. Among the four pesticide reduction technologies considered, healthy crop growth technology was the most appealing, followed by insect-proof net technology and biopesticide application technology. The least appealing was light trapping technology. The perceived income improvement from adopting these technologies was the main factor influencing farmers' willingness to adopt them, with a significant positive effect at a 1% confidence level.

The study conducted by Su *et al.* (2022) analyzed the basic characteristics of farmers, considering factors such as gender, age, education level, part-time employment, years of agricultural production, technology challenges, farm size (measured in mu), income structure, professional cooperatives, pesticide expenditure and family agricultural expenditure.

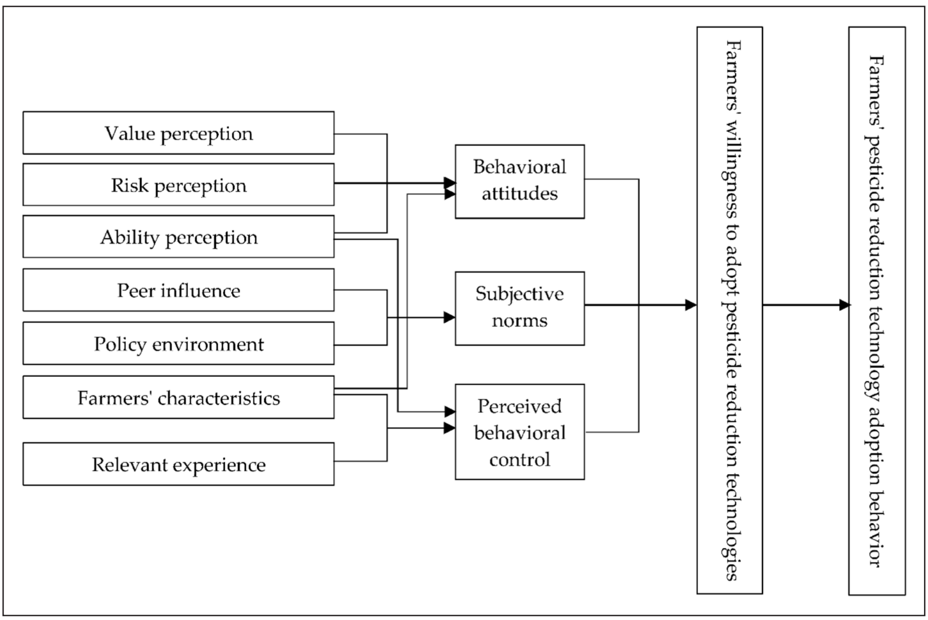

Figure 5: Farmers' response behavior to adoption of biopesticide utility

7. Conclusion

The main factors influencing the adoption of decision tools in IPM, factors such as technical limitations, farmers' attitudes towards adopting new technologies and tools, the ability of decision-making tools to address farmers' actual challenges, as well as their reliability and ease of use, are all important considerations. In Indian condition convening farmers about IPM and its utility it's very difficult due to continuously adjust farmers' practices in response to changing environmental and economic conditions. For large scale adoption of IMP governmental institution can take steps to awareness buildup among farmers. Still the cost of individual IMP component is very high because of it's the marginal farmers of India cannot effort biocontrol agents and bio-fertilizing agents. From the discussion cost and Knowledge constrains of IPM and its components plays a important role in adoption of IPM.

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